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Numerical Water Quality Model Study for the Los Angeles Harbor Pier 400 Project

by Ross W. Hall

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The Port of Los Angeles plans to construct an additional port facility referred to as Pier 400. The Pier 400 harbor facility may affect water quality by changing the tidal circulation and flushing patterns. Numerical water quality model simulations were used to compare flushing and dissolved oxygen (DO) resources at existing conditions and two stages of plan implementation.

The flushing simulations computed the transport and dilution of a conservative tracer inserted into various regions of the harbor. The flushing studies provided a qualitative comparison between plans where a decrease in flushing rate prolongs the period of time that oxygen-demanding substances exert their influence on the DO concentration.

The water quality simulations included the variables temperature, phytoplankton, phosphate, nitrate, biochemical oxygen demand, and DO, and were conducted for the period August 1-31, 1987, where a complete set of field data were available to establish initial and boundary conditions and to calibrate the model under existing conditions.

Two flushing studies were conducted: injection of tracer into all regions interior to the Federal breakwaters, and injection of tracer only in the region east of the Stage 1 access causeway. The first flushing study revealed that the two stages of plan implementation inhibited flushing in the LA Outer Harbor, Fish Harbor, Seaplane Lagoon, and Main

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Channel. The second flushing study showed that the access corridor prevented advection to areas west of the causeway; the dilution rate decreased by an order of three.

The water quality simulation indicated that DO concentrations remained nearly equivalent between existing and the two stages of plan implementation; all simulated DO concentrations exceeded 6.0 g m^{-3}. Plan implementations resulted in a small simulated DO decrease in the west side of the Los Angeles Outer Harbor, at the existing Terminal Island Treatment Plant (TITP) outfall, and in the Main Channel. The maximum DO difference of 1.5 g m^{-3} (8.6 g m^{-3} versus 7.5 g m^{-3}, for existing conditions and second plan implementation, respectively) occurred in the second week of the simulation in the bottom layer at the TITP outfall. Simulated DO east of the access causeway was higher for the plan implementations than under existing conditions.

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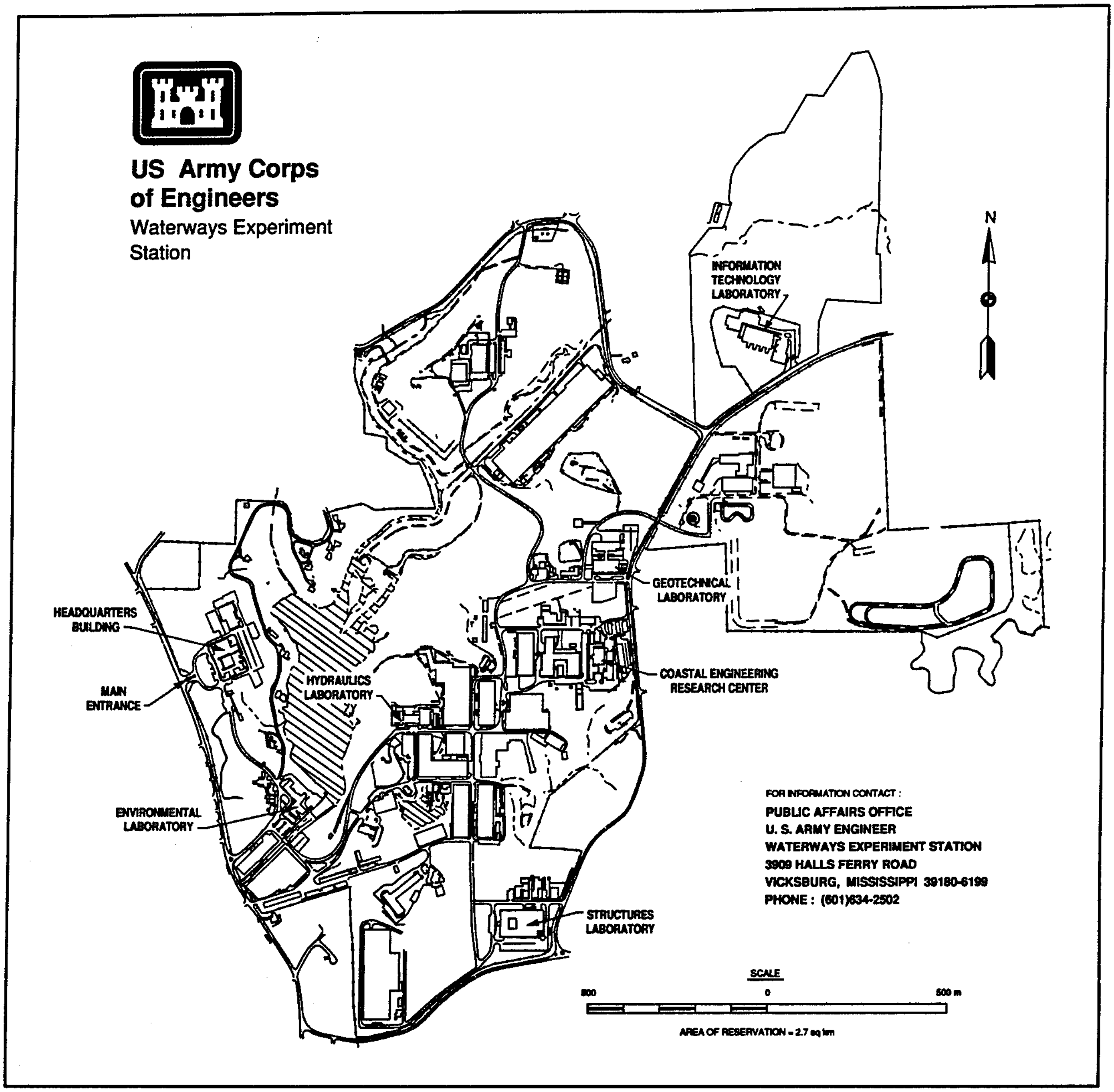

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Preface

The numerical water quality model study for the Los Angeles Harbor Pier 400 Project was conducted at the U.S. Army Engineer Waterways Experiment Station (WES) for the U.S. Army Engineer District, Los Angeles. Mr. Dennis G. Markle, Chief, Wave Processes Branch, Wave Dynamics Division, Coastal Engineering Research Center (CERC), was the WES study manager.

The study was conducted by Mr. Ross W. Hall of the Water Quality and Contaminant Modeling Branch (WQCMB), Environmental Processes and Effects Division (EPED), Environmental Laboratory (EL), WES. Dr. Harry Wang, CERC, coordinated and provided the hydrodynamic model output data used for the water quality simulations. Dr. Mark S. Dortch, Chief, WQCMB, provided direct supervision and report review. General supervision was provided by Mr. Donald L. Robey, Chief, EPED, and Dr. John Keeley, Director, EL.

At the time of publication of this report, Dr. Robert W. Whalin was Director of WES. COL Bruce K. Howard, EN, was Commander.

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1 Introduction

The Port of Los Angeles plans to construct an additional port facility, referred to as Pier 400. The Pier 400 harbor facility may affect water quality by changing the tidal circulation and flushing patterns. The objective of this study was to compare flushing and DO resources at existing conditions and at two stages of plan implementation. The comparisons were conducted through numerical model simulations.

The numerical water quality model (WQM) used for the comparisons was developed for the Los Angeles and Long Beach Harbors Model Enhancement Program (Hall 1990). The modeling technology consisted of three-dimensional, time-varying hydrodynamic and water quality models. The hydrodynamic model (HM) provides the circulation required by the transport terms of the WQM. The WQM is indirectly linked to the HM. Thus, the HM is applied, and the output is stored and subsequently used by the WQM.

This model application and the previous model enhancement study used water quality data, meteorological conditions, and tides measured during August 1987. However, the model enhancement study used three vertical layers, whereas this model application has five layers. Therefore, to demonstrate that the model could be used for the Pier 400 comparisons using five layers, the August 1987 conditions were included in the tests. The differences between the 1987 model enhancement study condition, the existing, and the two stages of plan implementation are the basin morphologies. Changes in the basin morphology result in changes in circulation used by the WQM. In this report the 1987 condition is referenced as "Base," the existing condition as "Existing," and the two stages of Pier 400 implementation as "POLA Stage 1" and "POLA Stage 2."

A discussion of the WQM used in this study is presented in Chapter 2. Chapter 3 describes the water quality and flushing comparisons, and Chapter 4 contains a summary of results and conclusions.

2 Water Quality Model

The WQM is an integrated compartment box model with enhanced horizontal and vertical transport schemes. Interface code is linked to the HM to write time-invariant data and temporally averaged flows. The water quality kinetic algorithms were adapted from the HydroQual, Inc., Potomac Estuary Eutrophication Model (Thomann and Fitzpatrick 1982).

Advective and Diffusive Transport Schemes

A modified version of QUICKEST (Quadratic Upstream Interpolation for Convective Kinematics with Estimated Streaming Terms) scheme (Leonard 1979, Hall and Chapman 1985) is implemented in the WQM. The QUICKEST implementation eliminated excessive numerical diffusion characteristic of upwind schemes or numerical instabilities characteristic of centered difference schemes.

The vertically stretched sigma coordinates in the hydrodynamic model account for much of the vertical advection through layer thickness expansion and contraction. As a consequence, the vertical velocities are small. However, the time step can be limited due to vertical diffusion. Therefore, an implicit vertical advective and diffusive transport scheme is implemented in order to use a larger time step. Central differences were used for both the advective and diffusive terms.

Model Linkage

The HM used for this study was CH3D (Curvilinear Hydrodynamics in Three Dimensions). The hydrodynamic and water quality models were linked by spatially and temporally averaging CH3D output to drive the WQM. The hydrodynamic model used extensive spatial resolution to resolve the flow field and to minimize the need for parameterization. The CH3D spatial resolution was on the order of 100 m and required a time step of 60 sec for stability. In contrast, the WQM has characteristic time scales on the order of hours, which are determined by the kinetic rate coefficients. The desired analyses of water

quality allow a spatial resolution an order of magnitude less than that used by CH3D. The larger horizontal WQM grid size allowed the use of a time step of 900 sec. Both CH3D and the WQM used five vertical layers.

Vertical diffusivities were calculated in CH3D. The linked interface code temporally averaged the calculated values and included the averaged vertical diffusivities in the hydrodynamic information written for subsequent use by the WQM. However, since temperature and salinity simulations were not an objective of the HM task, precise tuning of CH3D temperature and salinity calculations to provide vertical diffusivities was not conducted. As a result the temporally averaged vertical diffusivities were generally 0.001 m^2 sec^{-1}. Vertical diffusivities of 0.001 m^2 sec^{-1} in the WQM resulted in uniform vertical distributions of DO in the WQM. A systematic decrease in the magnitude of vertically diffusivities in the WQM indicated that the use of a spatially constant value of 0.0001 m^2 sec^{-1} resulted in simulated vertical distributions matching measured values. Field dye studies conducted by Tekmarine (1987) provided an order of magnitude estimate for the horizontal diffusion coefficient of 1 m^2 sec^{-1} (Fisher et al. 1979).

The HM grids, WQM grids, and WQM grids overlaying the HM grids are displayed as follows:

Plate	Plot
1	Base HM Grid
2	Base WQM Grid
3	Base WQM Grid Overlaid
4	Existing HM Grid
5	Existing WQM Grid
6	Existing WQM Grid Overlaid
7	POLA Stage 1 HM Grid
8	POLA Stage 1 WQM Grid
9	POLA Stage 1 WQM Grid Overlaid
10	POLA Stage 2 HM Grid
11	POLA Stage 2 WQM Grid
12	POLA Stage 2 WQM Grid Overlaid

Kinetic Routines

The WQM kinetic code included eight variables for which measured data were available and were used to monitor model results. These variables are referred to as state variables and include

a. Temperature.

b. Tracer.

c. Phytoplankton.

d. PO_4-P (dissolved phosphate).

e. NH_4-N (ammonium).

f. NO_2+NO_3-N (nitrite plus nitrate).

g. $CBOD_5$ (5-day biochemical oxygen demand).

h. DO (dissolved oxygen).

Temperature is a primary determinant of the rate of biochemical reactions. Tracer was a conservative state variable used for the flushing analyses. The remaining state variables, phytoplankton through DO, were transported, interacted with each other, and added or deleted through boundaries or sources and sinks. Phytoplankton biomass was modeled as carbon. However, phytoplankton biomass was reported in chlorophyll-a (Tekmarine 1987). A carbon to chlorophyll (C/Chl) ratio of 80.0 was used to convert chlorophyll to carbon. Phytoplankton are referenced as algae in the tables. The kinetic routines are described in Hall (1990). The kinetic constants used are listed in Table 1.

Salinity influences the saturation concentration of DO. Salinity was set constant at 32 parts per thousand ($^0/_{00}$). A constant reaeration coefficient of 1.0 m day^{-1} was used for the water quality simulations. The application of O'Connor's (1983) relationship between wind speed and reaeration resulted in a daily average reaeration coefficient for San Pedro Bay that varied between 0.96 and 1.02 m day^{-1} (Hall 1990).

Initial Conditions

The WQM simulation extended from August 1-31, 1987. Initial conditions were specified for each of the WQM state variables and for each cell at the initiation of the simulation. The water quality data collected by Tekmarine (1987) on August 4, 1987, were used to specify initial conditions.

Examination of the data revealed minor horizontal spatial variability and similar vertical distributions among stations. Temperature and DO were measured at 2-m intervals. Chlorophyll-a, $CBOD_5$, and the nutrients PO_4-P, NH_4-N, and NO_2+NO_3-N were measured 1 m below the surface, middepth, and 1 m above the bottom. No detectable chlorophyll-a or $CBOD_5$ was measured August 4, 1987, interior to the breakwaters.

Table 1
Kinetic Constants

Description	Unit
Solar radiation attenuation constant	0.50 m^{-1}
Light intensity at maximum algal photosynthesis	70.0 W m^{-2}
Fraction of daylength	0.5
Half-saturation constant for nitrogen	0.025 g N m^{-3}
Half-saturation constant for phosphorus	0.001 g P m^{-3}
Saturated algal growth rate at 20 °C	2.0 day^{-1}
Temperature coefficient for algal growth	1.068
Algal respiration rate at 20 °C	0.1875 day^{-1}
Temperature coefficient for algal respiration	1.045
Algal maximum excretion rate	0.03 day^{-1}
Algal mortality rate at 20 °C	0.02 day^{-1}
Algal settling velocity	0.1 m day^{-1}
Phosphorus to carbon ratio	0.025 g P (g C)$^{-1}$
CBOD deoxygenation rate at 20 °C	0.2 day^{-1}
Temperature coefficient for CBOD deoxygenation	1.047
Half-saturation constant for CBOD	0.5 g O_2 m^{-3}
Ratio of ultimate CBOD to $CBOD_5$	1.85
Oxygen to carbon ratio	2.67 g O_2 (g C)$^{-1}$
Nitrogen to carbon ratio	0.25 g N (g C)$^{-1}$
Nitrification rate at 20 °C	0.1 day^{-1}
Temperature coefficient for nitrification	1.08
Half-saturation constant for nitrification	2.0 g O_2 m^{-3}
Temperature coefficient for SOD	1.08
Half-saturation constant for SOD	0.5 g O_2 m^{-3}

Because of the observed spatial distribution, sample depths, and absence of detectable measurements, the following procedures were used to assign initial conditions:

a. Nondetectable measurements were assigned a value equal to one-half the detection limit (Table 2).

b. Initial conditions were assumed horizontally constant but varied with depth. Temperature and DO measurements were assigned to a layer based on the depth of measurement. For the constituents measured at three levels, the surface value was assigned to layer 1, the bottom value assigned to layer 5, and the middepth value assigned to layer 3. The layers were numbered from the surface to the bottom.

Table 2 Water Quality Constituent Detection Limits	
Constituent	**Detection Limit**
Chlorophyll-a	4.0 mg m^{-3}
$CBOD_5$	1.0 g m^{-3}
PO_4-P	0.02 g m^{-3}
NH_4-N	0.01 g m^{-3}
NO_2+NO_3-N	0.01 g m^{-3}

c. Constituent layer values were calculated through arithmetic averaging. The averaging procedure provided initial condition values for temperature and DO for each of the five layers Averaging provided values for the surface, middepth, and bottom for the remaining constituents; values for layers 2 and 4 were calculated as the arithmetic average of adjacent layers (Table 3).

Table 3
Initial Conditions (Based on Laboratory Analysis)

Constituent	Layer 1	2	3	4	5
Temperature °C	18.5	17.2	15.8	14.9	14.2
DO g O_2 m^{-3}	9.3	9.1	8.1	7.1	6.3
Algae g C m^{-3}	0.16	0.16	0.16	0.16	0.16
$CBOD_5$ g O_2 m^{-3}	0.5	0.5	0.5	0.5	0.5
PO_4 g P m^{-3}	0.16	0.14	0.12	0.12	0.13
NH_4 g N m^{-3}	0.010	0.008	0.007	0.007	0.007
NO_2+NO_3 g N m^{-3}	0.11	0.07	0.03	0.04	0.06

Notes: C/Chl = 80.0. Nondetectable observations assigned values = 0.5 detection limit.

Boundary Conditions

Boundary conditions included observed water quality at the ocean boundary, sediment oxygen demand (SOD) at the bottom, and light exchange through the surface.

Solar radiation at the water surface was computed from meteorological information. The computed solar radiation values were used in the algal growth computations. Meteorological information was acquired from the National Oceanic and Atmospheric Administration's Tape Deck No. 1440

WBAN Hourly Surface Observations for the Long Beach Airport (Station No. 5085). Computations for solar radiation were based on a Heat Exchange Program (Eiker 1977).

Examination of measured SOD data (Table 4) indicated that values varied between 1.31 and 2.63 g O_2 m^{-2} day^{-1}. Because of the uncertainties associated with SOD (e.g. measurement techniques are not well established and SOD varies with time and overlying DO concentration), a constant, "representative" value of 2.0 g O_2 m^{-2} day^{-1} was used.

Table 4
Sediment Oxygen Demand Measurements

Station Number	SOD Measurement g O_2 m^{-2} day^{-1}	Average SOD g O_2 m^{-2} day^{-1}	Station Location
Trial	2.08	2.08	West LA Outer Harbor
I-4	2.63 1.63	2.14	East Basin Channel
I-10	1.82	1.82	Cerritos Channel
I-3	1.31	1.31	LA Outer Harbor
I-11	1.63 1.53	1.58	Middle Harbor
I-8	1.75 1.67	1.71	LB Outer Harbor

The constituents phytoplankton, PO_4-P, NH_4-N, NO_3-N, and $CBOD_5$ were set constant (Table 5). The constituent values were an average of all boundary measurements (Tekmarine 1987). Nondetectable measurements were set equal to one-half their detection limit.

Table 5
Temporally and Spatially Constant Boundary Conditions

Constituent	Value
Algae g C m^{-3}	0.2256
PO_4 g P m^{-3}	0.0726
NH_4 g N m^{-3}	0.0121
NO_3 g N m^{-3}	0.0297
$CBOD_5$	0.6300

The dissolved oxygen and temperature at the ocean boundary were specified by linearly interpolating in both space and time the measured data. Tables 6 and 7 summarize the dissolved oxygen and temperature data used for the ocean boundary.

Table 6
Dissolved Oxygen (g DO m^{-3}) for Boundary Stations B1, B2, and B3

Julian Day	Layer				
	1	2	3	4	5
Station B1					
216.5	9.0	8.9	8.4	7.8	6.8
223.5	9.7	9.8	9.6	9.5	9.1
230.5	9.0	9.3	9.1	9.9	8.4
237.5	8.5	8.8	8.8	8.9	8.4
Station B2					
216.5	10.6	10.6	10.2	9.3	8.2
223.5	9.7	10.4	9.6	10.0	9.1
230.5	9.0	9.8	9.1	10.2	8.6
237.5	8.9	8.9	8.6	8.3	8.0
Station B3					
216.5	11.0	11.9	10.7	10.9	10.0
223.5	9.7	10.9	9.6	10.6	9.1
230.5	9.1	10.4	9.1	10.4	8.8
237.5	10.3	11.3	9.4	9.9	8.7

Table 7
Temperature (°C) for Boundary Stations B1, B2, and B3

Julian Day	Layer 1	2	3	4	5
Station B1					
216.5	16.1	15.1	14.2	13.5	12.7
223.5	20.4	19.6	18.5	17.8	17.2
230.5	20.4	20.2	18.8	19.0	15.5
237.5	20.7	20.0	18.7	17.9	16.5
Station B2					
216.5	19.8	18.4	16.7	15.4	14.4
223.5	21.2	21.4	19.0	19.5	17.6
230.5	20.8	21.8	19.3	20.2	16.6
237.5	19.5	19.0	18.2	16.9	15.8
Station B3					
216.5	21.8	21.4	18.2	18.2	17.0
223.5	22.1	23.2	19.6	21.2	17.9
230.5	21.2	23.5	19.8	21.3	17.7
237.5	20.8	22.5	18.8	20.0	17.3

3 Existing and Plan Flushing and Water Quality Comparison

The flushing studies consisted of insertion of a conservative tracer and noting the movement and dilution of the tracer. The flushing studies provided a qualitative comparison between Existing and Pier 400 implementation conditions. A decrease in the flushing rate prolongs the period of time that oxygen-demanding substances exert their influence on the DO concentration. The water quality simulations included the state variables temperature, phytoplankton, PO_4-P, NH_4-N, NO_3+NO_2-N, $CBOD_5$, and DO. Emphasis was on the DO.

Flushing Comparison

The existing WQM grid was modified so that the WQM cells east of the access causeway coincided with the two stages of the Pier 400 implementation (Plates 13 and 14). The modified existing WQM grid are referenced as "Existx." The grid was modified because emphasis was directed toward assessment of flushing in the lagoon area east of the causeway. A comparison of Plate 6 (Existing WQM Grid Overlaid) with Plate 14 (Modified Existing WQM Grid Overlaid) indicates that the lagoon area was divided into two WQM cells corresponding to the cell structure of POLA Stage 1 (Plate 9) and POLA Stage 2 (Plate 12). Bold arrows were drawn on Plate 13 to emphasize the location of the two WQM cells.

Flushing studies

Two flushing studies were conducted: insertion of tracer in all WQM cells interior to the breakwater, and insertion of tracer in the WQM cell east of the proposed access causeway (WQ Station X-11).

The first flushing study identified patterns of flushing and compared differences between existing and Pier 400 implementation conditions. The flushing study with insertion of tracer in the WQM cell east of the proposed access

causeway was conducted to document changes in flushing due to construction of the access causeway.

The conservative tracer was uniformly inserted into the five layers of the water column at a concentration of 10.0 units m^{-3} at a time corresponding to 0000 hr August 1, 1987. Tracer transport was simulated for 30 days. For the first flushing study (insertion of tracer in all the WQM cells), the boundaries were specified exterior to the breakwaters. Tracer could exit the outer harbor through the breakwater openings, but only water without tracer material could enter the outer harbor from the ocean boundary.

Shade plots and graphs showing dilution of the tracer are displayed in Appendix A.

Flushing results

Shade plots of the first flushing experiment are displayed in Plates A1-A9. A blank cell indicates that the simulated tracer concentration was less than 1.0 unit m^{-3}. Examination of Plates A1-A3 reveals that the pattern and magnitude of tracer dilution were nearly equivalent after 5 days for Existing, POLA Stage 1, and POLA Stage 2 conditions. However, examination of shade plots after 15 days (Plates A4-A6) and 25 days (Plates A7-A9) reveals that

a. POLA Stage 1 and Stage 2 conditions inhibit flushing in the LA Outer Harbor, Fish Harbor, Seaplane Lagoon, and Main Channel.

b. Flushing patterns are similar for both POLA Stage 1 and Stage 2.

It is important to note that the insertion of tracer in all WQM cells provides information on global flushing but provides little information on flushing at specific sites. For example, the shade plots indicates that high concentration of tracer remains in the Seaplane Lagoon throughout the 30-day simulation period. Similarly, the shade plots reveal that high concentrations of tracer remain in water adjacent to the Seaplane Lagoon. Any tracer flushed from the Lagoon would be replaced with adjacent water with high tracer concentration.

Results of the second flushing study, insertion of tracer in the WQM cell east of the proposed causeway, is displayed using a time series plot showing tracer concentration with time (Plate A10). Examination of Plate A10 indicates that flushing is equivalent in both POLA Stage 1 and POLA Stage 2 conditions. Existing conditions required 2.5 days for the tracer to be diluted 90 percent, while POLA Stage 1 and 2 conditions required 7.5 days. Examination of the WQM grid for the existing condition (Plates 13 and 14) shows that advection to cells west of the insertion point was possible because of the absence of the planed access causeway. A shade plot (Plate A11) of a snapshot taken 2.5 days after tracer insertion in the existing condition shows that tracer was transported to cells west of the insertion point.

The access causeway prevented tracer advection to cells west of the insertion point. Examination of the shade plot for the POLA Stage 2 condition (Plate A12) reveals no tracer west of the access causeway.

Water Quality Comparison

Two techniques were used to compare measured data with Base, Existing, POLA Stage 1, and POLA Stage 2 simulations: time series plots, and vertical profile plots.

Snapshots of the simulations were made to correspond to the time of collection of measured data. The snapshots were then displayed as time series and vertical profile plots. The location and naming convention of points used for comparison (displayed in Plates 15-18) is described below.

Plate	Plot
15	Water Quality Stations - Base
16	Water Quality Stations - Existing
17	Water Quality Stations - POLA Stage 1
18	Water Quality Stations - POLA Stage 2

The prefix "I" refers to the interior stations, and the prefix "B" refers to the boundary stations sampled by Tekmarine. The prefix "X" represents the extra locations selected for more complete coverage of the study area. The stations in each of the simulations correspond to the same physical location; Plates 15-18 provide guidance in locating station locations relative to plan morphology. The water quality stations and the centroid of the water quality cell used to represent the stations are listed in Table 8. The centroid is represented as hydrodynamic grid cell coordinates (i,j).

Time series

The water quality constituents phytoplankton, PO_4-P, NH_4-N, NO_3+NO_2-N, $CBOD_5$, and DO are displayed as time series for the surface (layer 1) and bottom (layer 5) layers. Snapshots were made at 1200 hr August 4 (Julian Day 216), August 11 (Julian Day 224), August 18 (Julian Day 230), and August 25 (Julian Day 237). The snapshot values were linearly interpolated between snapshot dates and displayed in the time series plots in Appendix B.

Table 8 Water Quality Stations			
Station Number	HM Grid		Description
	I	j	
I-01	14	48	Main Channel
I-02	26	48	TITP Outfall
I-03	26	37	LA Outer Harbor
I-04	26	27	East Basin Channel
I-05	49	60	Middle Harbor
I-06	57	69	Back Channel
I-07	82	62	LA River Mouth
I-08	75	29	LB Outer Harbor
I-09	98	20	SE of Island Freeman
I-10	38	81	Cerritos Channel
I-11	57	60	Middle Harbor
B-01	26	18	Angels Gate Entrance
B-02	73	18	Queens Gate Entrance
B-03	108	13	E LB Breakwater
X-01	22	90	LA West Basin
X-02	40	91	Consolidated Slip
X-03	12	80	LA Southwest Slip
X-04	64	82	LB Channel Two
X-05	64	77	LB Channel Three
X-06	31	64	Seaplane Lagoon
X-07	38	64	Naval Basin
X-08	6	44	LA West Channel
X-09	68	63	LB East Basin
X-10	44	45	LB Outer Harbor
X-11	35	64	Access Causeway
X-12	3	25	San Pedro Breakwater

Vertical profiles

Examination of the time series plots revealed DO differences between measured data, Existing, POLA Stage 1, and POLA Stage 2 conditions for Stations I-01, I-02, I-07, and X-12. The water quality snapshots for these stations were displayed using vertical profiles. Station X-11, the location east of access causeway, was included in the vertical profiles. The vertical profile plots are displayed in Appendix C.

Results

Examination of water quality simulation results of Base and Existing conditions indicates that Base and Existing conditions were nearly equivalent.

The measured and simulated results for the Base and Existing conditions were in general agreement except for Stations I-2 (Plates B2, B28, C1, C6, C11, and C16) and I-7 (Plates B7, B33, C3, C8, C13, and C18). Station I-2 was located at the Terminal Island Treatment Plant (TITP) outfall, and the measured constituent values reflected the effluent conditions during August 1987. All the model simulations did not include the TITP effluents. The TITP outfall effluent was not modeled because other organizations responsible for the TITP outfall have modeling responsibility for impacts separate from Pier 400. The TITP outfall will be relocated in the future regardless of harbor expansion plans.

Examination of the plots for Station I-7 reveals that the Los Angeles River is contributing some flows to the bay that were not modeled. The water quality sampling program conducted by Tekmarine revealed less saline, as well as nutrient-, $CBOD_5$-, and chlorophyll-enriched water at Station I-7. The profile plots for Station I-7 (Plates C3, C8, C13, and C18) indicate that the Los Angeles River may have deposited organic-enriched sediments at the location, resulting in increased sediment oxygen demand. An increased SOD would be indicated by DO gradients with maximum DO at the surface decreasing to minimum DO at the bottom. Measured DO with surface concentrations exceeding 10.0 and bottom concentrations less than 4.0 g DO m^{-3} were measured at Station I-7.

A comparison of Existing, POLA Stage 1, and POLA Stage 2 water quality time series and profile plots reveals that maximum differences in DO occurred at Station I-01 (Main Channel), I-02 (TITP Outfall), and X-12 (San Pedro Breakwater). An examination of the time series plots indicates:

a. Maximum differences occurred the second week of simulation (Julian Day 223.5).

b. Simulated DO was nearly equivalent at the beginning and end of the simulation period. The similarity at the beginning of the simulation period was due to the same initial conditions. The simulated differences the second week may be a transient response, and the similarity at the end of the simulation period may reflect that water quality conditions following Pier 400 implementation are similar to existing conditions.

c. Maximum differences between Existing and the Pier 400 implementations in DO occurred in the bottom layer at Station I-02 at Julian Day 237.5. The simulated existing DO was 8.6 while POLA Stage 1 was 7.2 and POLA Stage 2 was 7.1 g DO m^{-3}. The simulated bottom layer

DO differences between Existing and the Pier 400 implementations were near 1.5 g DO m^{-3}; in contrast, surface layer differences were less than 1.0 g DO m^{-3}.

d. The maximum simulated differences in DO at Station I-01 occurred at the surface. Existing surface DO was 8.6 g DO m^{-3} while POLA Stage 1 was 8.1 and POLA Stage 2 was 7.9 g DO m^{-3}. The simulated differences were less than 1.0 g DO m^{-3}.

e. The Pier 400 implementations decreased the simulated surface and bottom DO at Station X-12. Surface DO decreased about 1.1, and bottom DO decreased 0.5 g DO m^{-3}.

f. Examination of the simulated DO at Station X-11, located at the embayment east of the access causeway, revealed that simulated DO was greater in the Pier 400 implementations than in the Existing conditions (Plates B25, B51, C4, C9, C14, and C19). Maximum differences occurred the second week of simulation, with both surface and bottom DO in the Pier 400 implementations exceeding existing conditions by 0.3 g DO m^{-3}.

Generally, the simulated DO differences between the Existing and Pier 400 implementation conditions were minimal. Simulated DO decreased slightly in the Los Angeles Outer Harbor and Main Channel following Pier 400 stage implementations. The magnitude of the DO differences increased with further plan implementation; that is, POLA Stage 2 resulted in lower DO concentrations than POLA Stage 1, and POLA Stage 1 resulted in lower DO than Existing. The only model input differences between Existing and the Pier 400 implementations were changes in basin morphology due to dredge and fill. Simulated differences were due to changes in circulation and flushing as indicated, with inhibited flushing in the LA Outer Harbor, Fish Harbor, Seaplane Lagoon, and Main Channel following Pier 400 implementation. The flushing studies indicated a change in circulation and flushing.

4 Summary and Conclusions

A numerical water quality model was applied to San Pedro Bay, and simulation results for Existing and POLA Stage 1 and POLA Stage 2 implementations of the Pier 400 port facility were compared. The focus of the study was to compare flushing and DO resources.

The flushing studies consisted of insertion of a conservative tracer and noting movement and dilution of the tracer. A flushing study with insertion of tracer in all WQM cells indicated that the Pier 400 implementation inhibited global flushing on the west side of the Los Angeles Outer Harbor.

The insertion of tracer in the WQM cell east of the proposed access causeway revealed that construction of the causeway resulted in a 300 percent decrease in the rate of dilution.

The water quality results indicate that the simulated DO is nearly equivalent between Existing and the Pier 400 conditions. Maximum differences in DO occurred in the west side of the Los Angeles Outer Harbor. Decreases in DO were noted in the Main Channel, the prior TITP effluent location, and in the Outer Harbor interior to the San Pedro Breakwater. The maximum decrease in DO occurred at the prior TITP effluent location, located north of the Pier 400 landfill. The simulated bottom layer DO for POLA Stage 2 was 7.1 g DO m^{-3}, a decrease of nearly 1.5 g DO m^{-3} from Existing conditions. The simulated DO concentration of 7.1 g DO m^{-3} is near 90 percent of DO saturation at the measured temperature and salinity. The simulated DO concentration is adequate to maintain the existing aquatic biota. Surface layer differences were less than 1.0 g DO m^{-3}.

Examination of the simulated DO in the embayment east of the access causeway revealed that simulated DO was greater in the Pier 400 implementations than in the Existing conditions. DO in the Pier 400 implementations exceeded Existing conditions a maximum of 0.3 g DO m^{-3}.

Examination of results for Existing, POLA Stage 1, and POLA Stage 2 indicates that simulated DO exceeds 6.0 g DO m^{-3} for all sampled stations.

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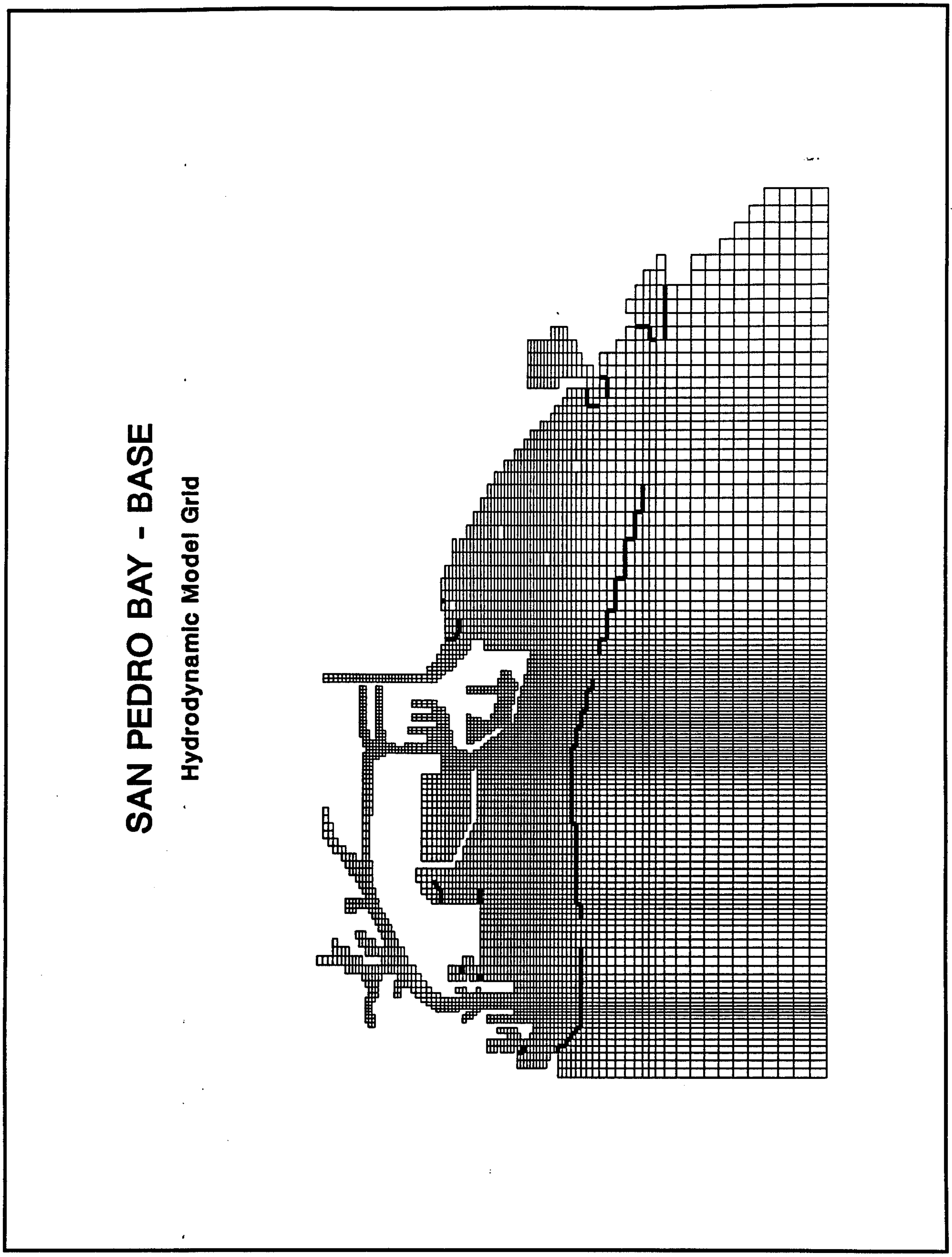

SAN PEDRO BAY - BASE
Hydrodynamic Model Grid

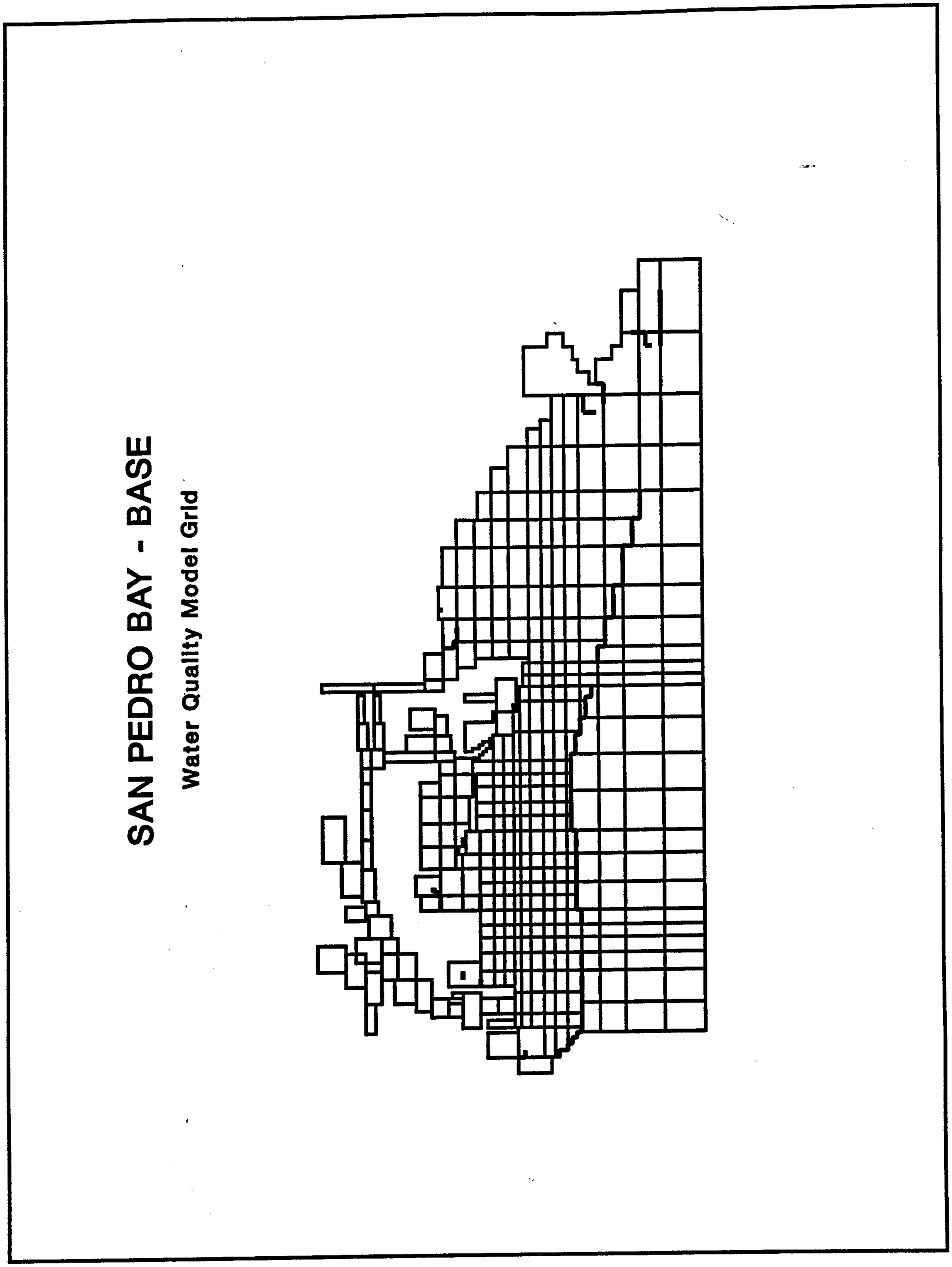
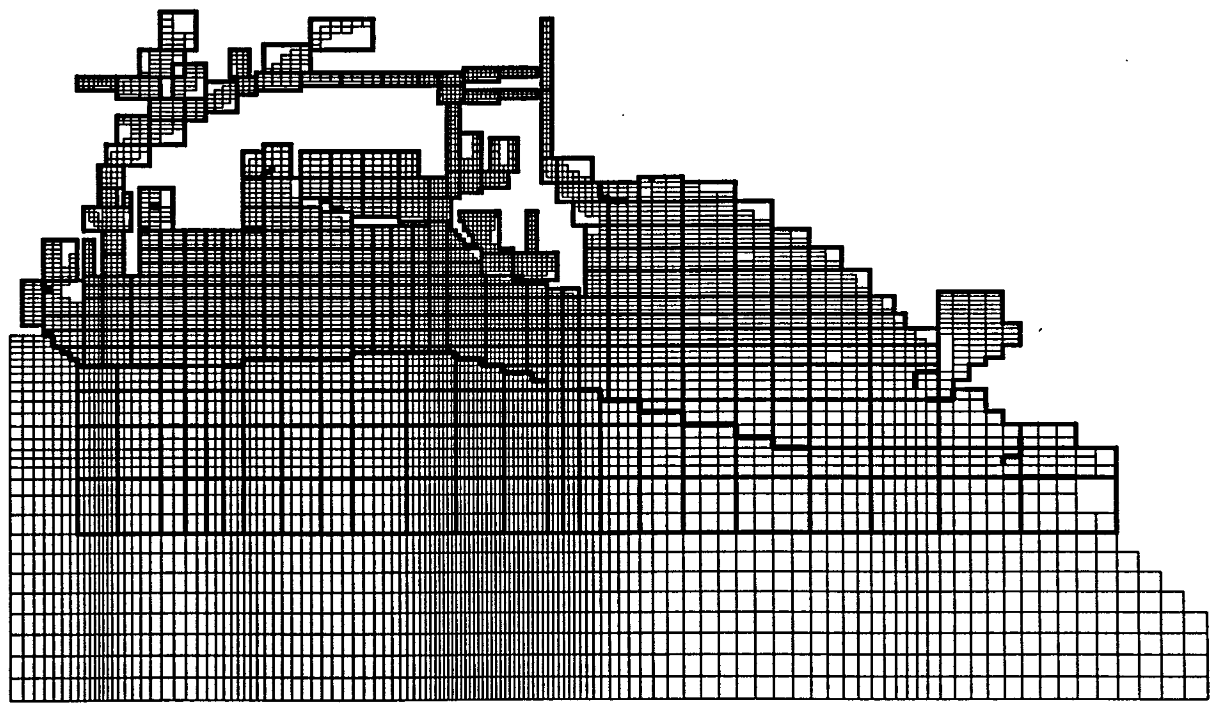


Plate 2

SAN PEDRO BAY - BASE

Water Quality Model Grid Overlaid



SAN PEDRO BAY - EXISTING

Hydrodynamic Model Grid

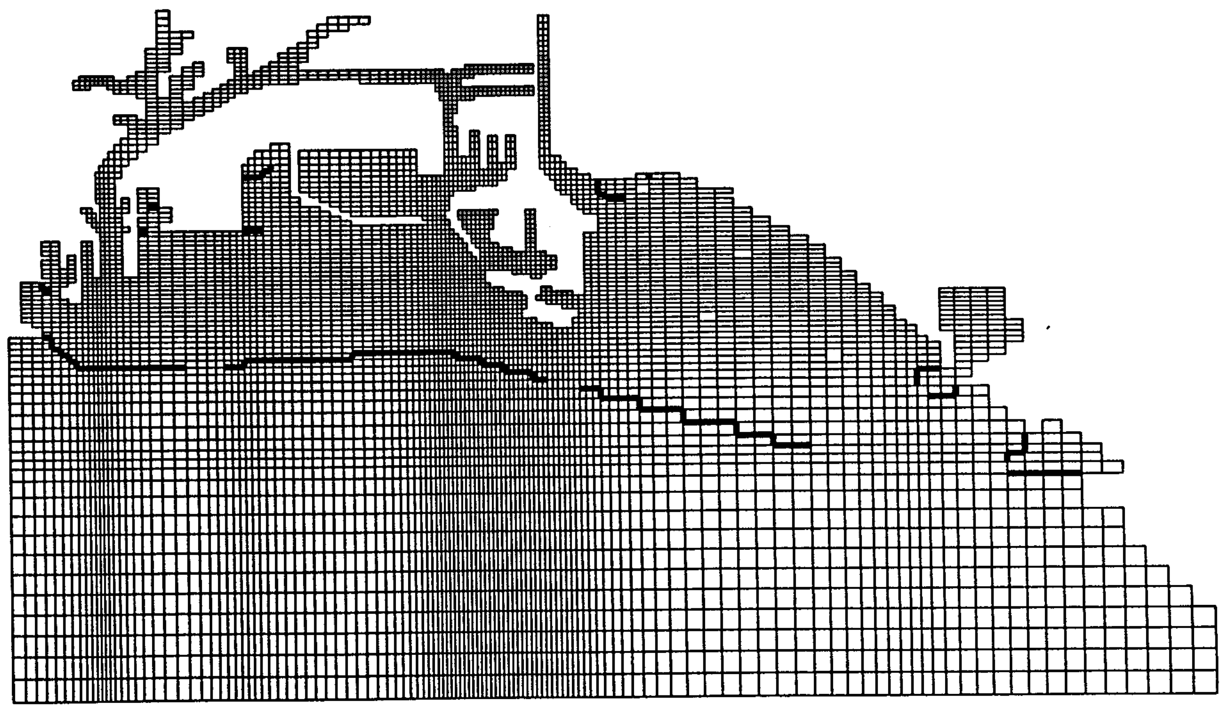
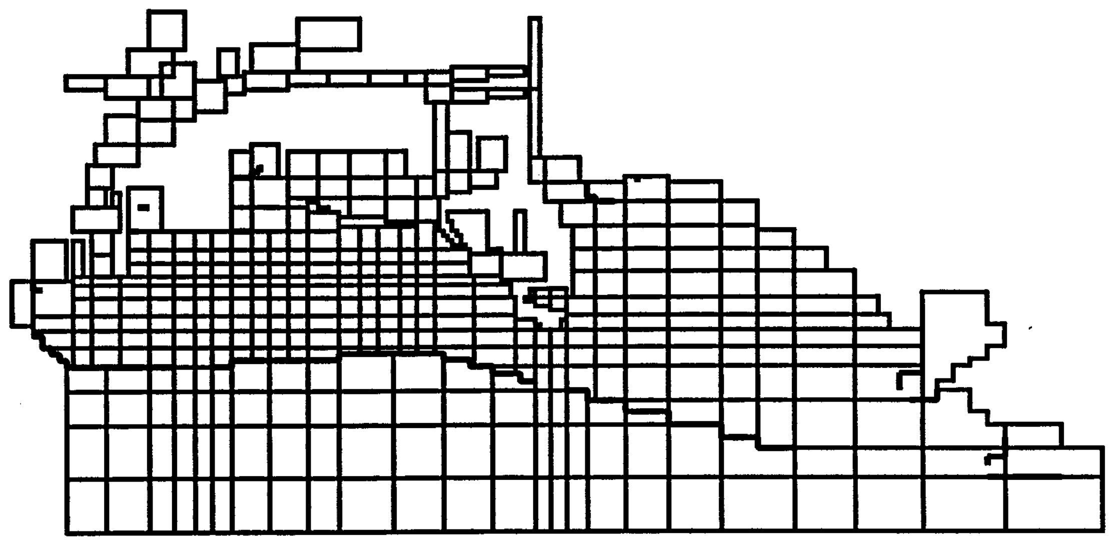


Plate 4

SAN PEDRO BAY - EXISTING

Water Quality Model Grid



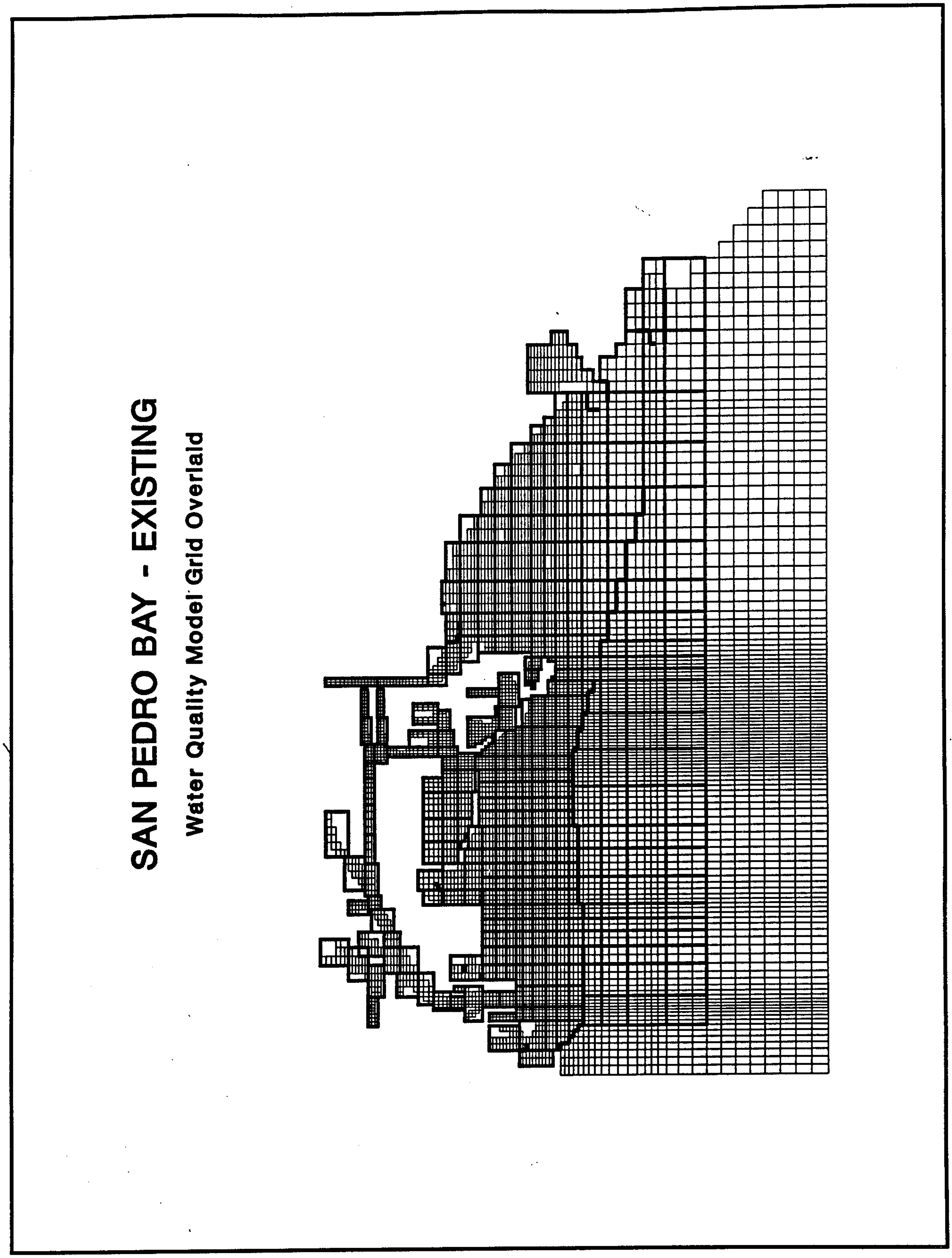
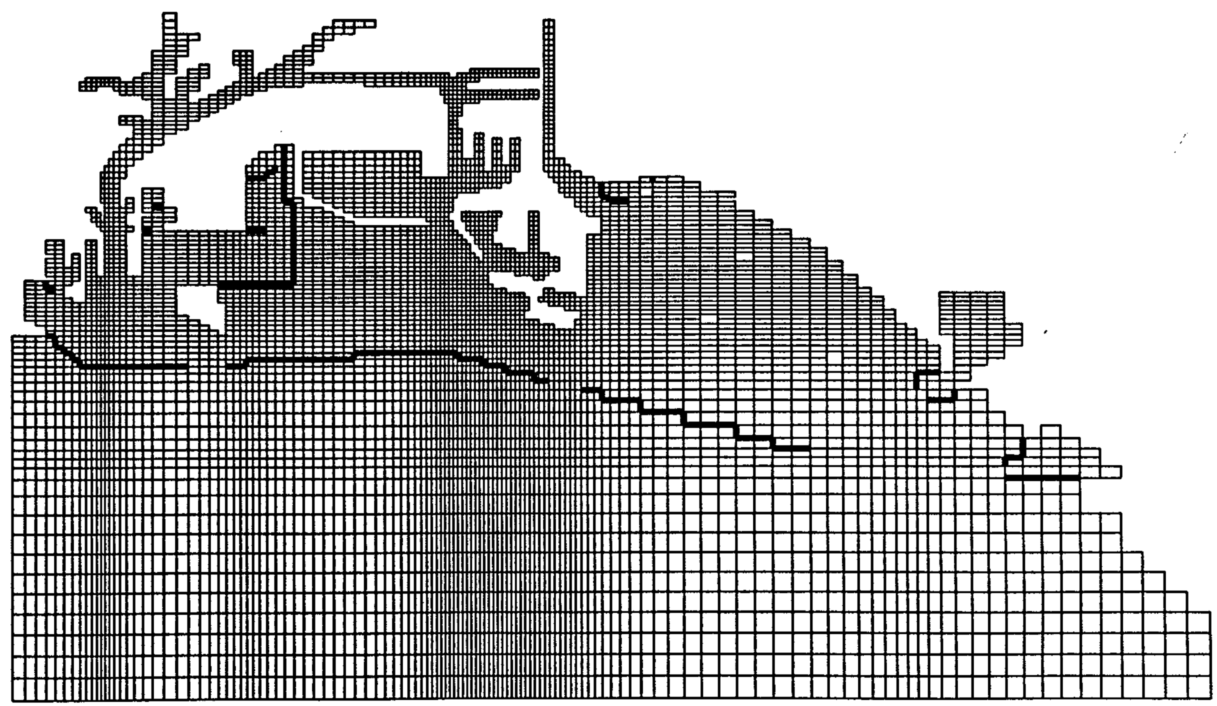


Plate 6

SAN PEDRO BAY - POLA STAGE 1

Hydrodynamic Model Grid



SAN PEDRO BAY - POLA STAGE 1

Water Quality Model Grid

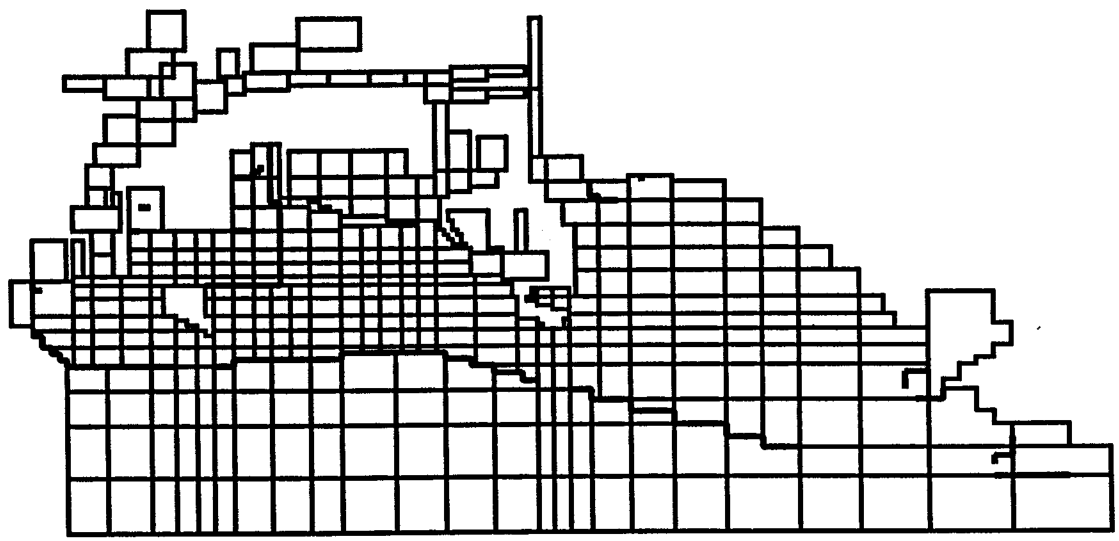
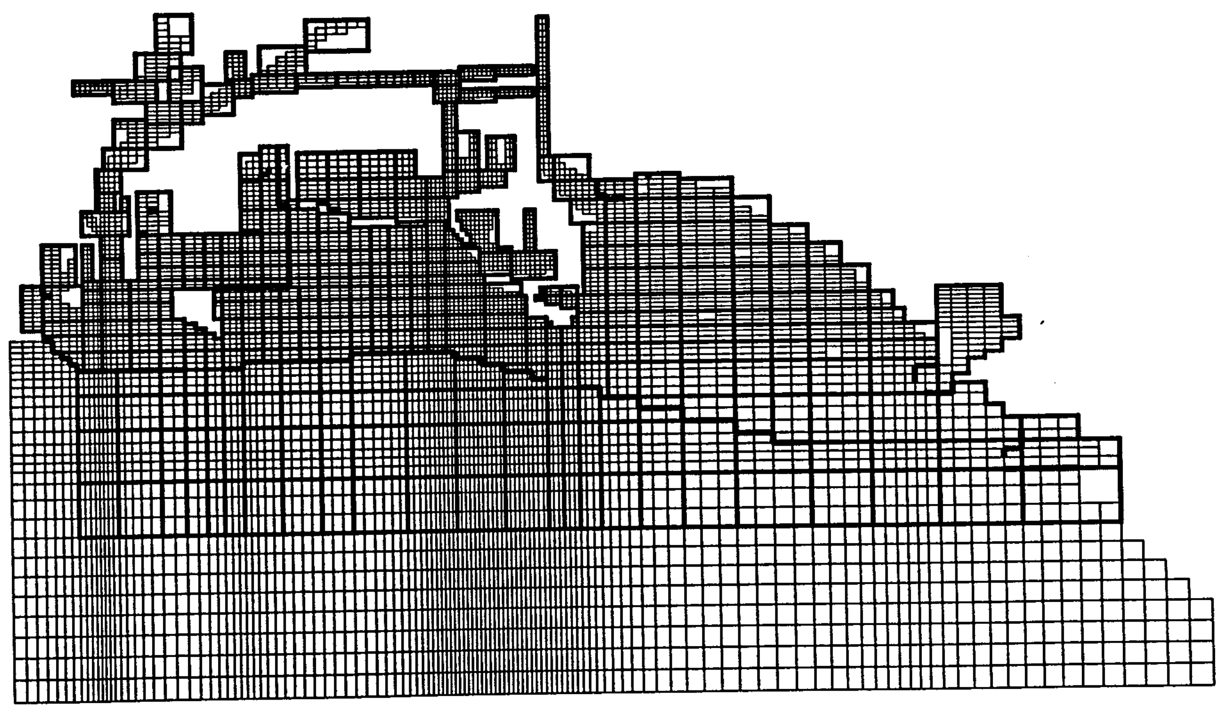


Plate 8

SAN PEDRO BAY - POLA STAGE 1

Water Quality Model Grid Overlaid



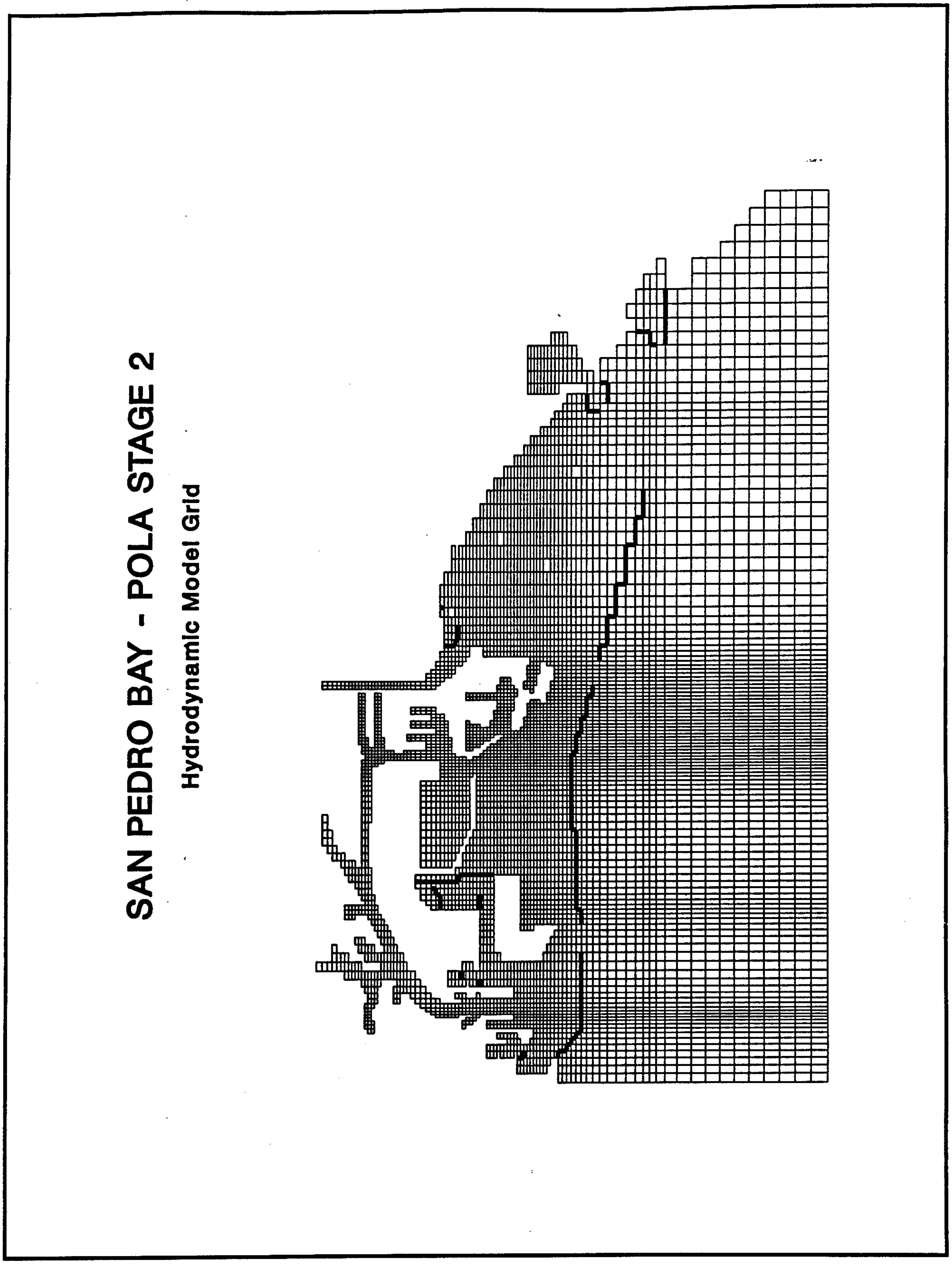
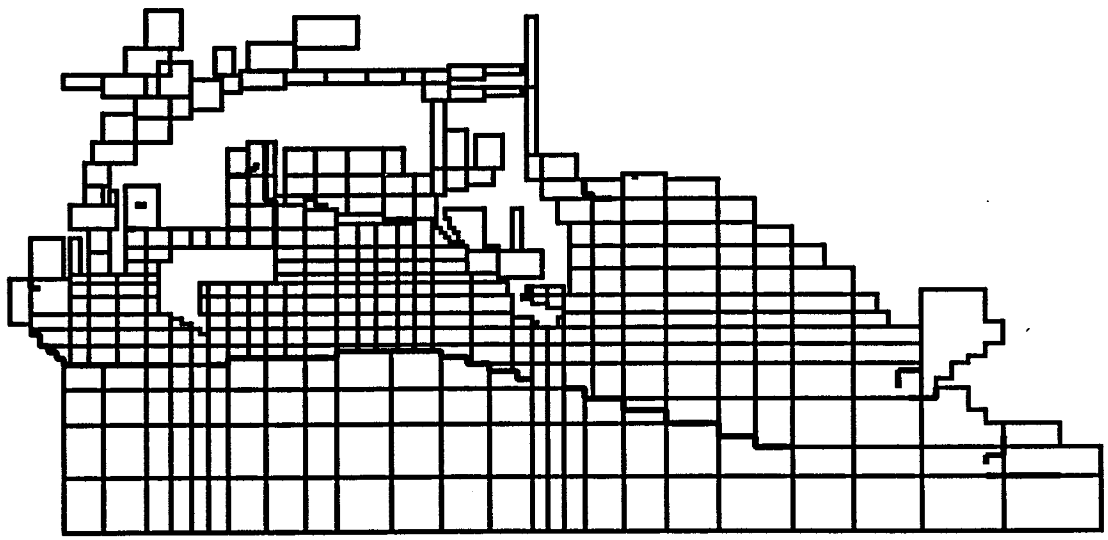


Plate 10

SAN PEDRO BAY - POLA STAGE 2

Water Quality Model Grid



SAN PEDRO BAY - POLA STAGE 2

Water Quality Model Grid Overlaid

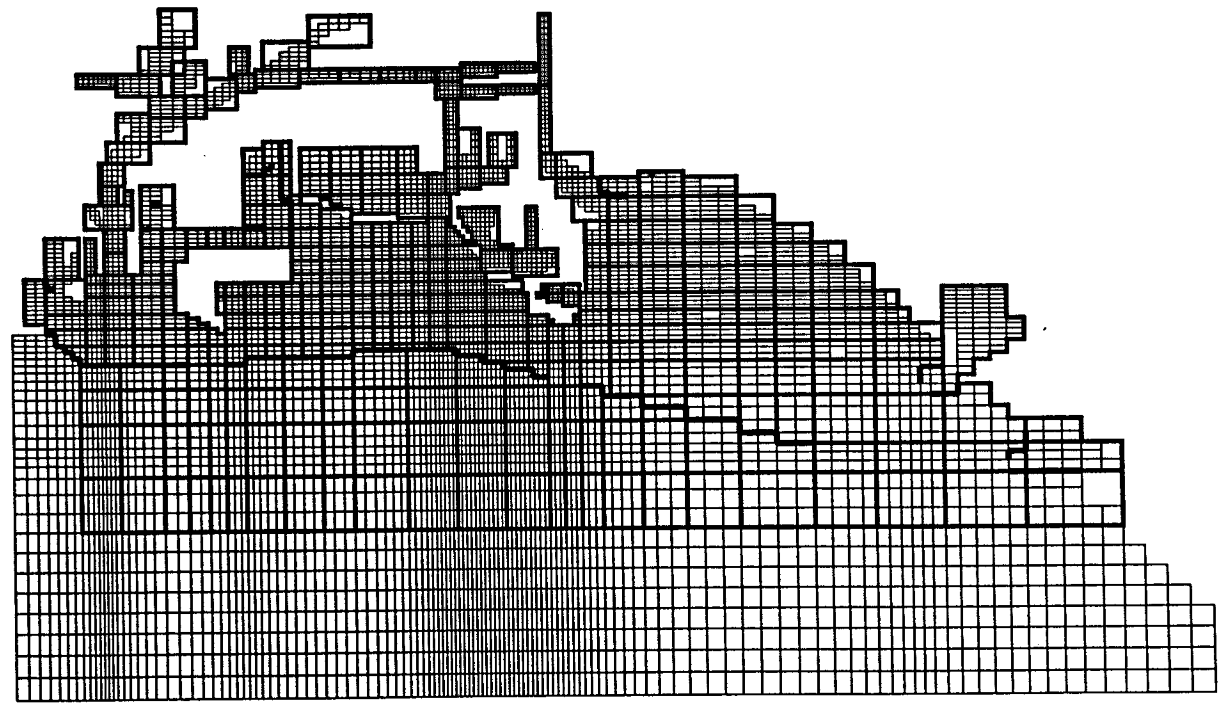
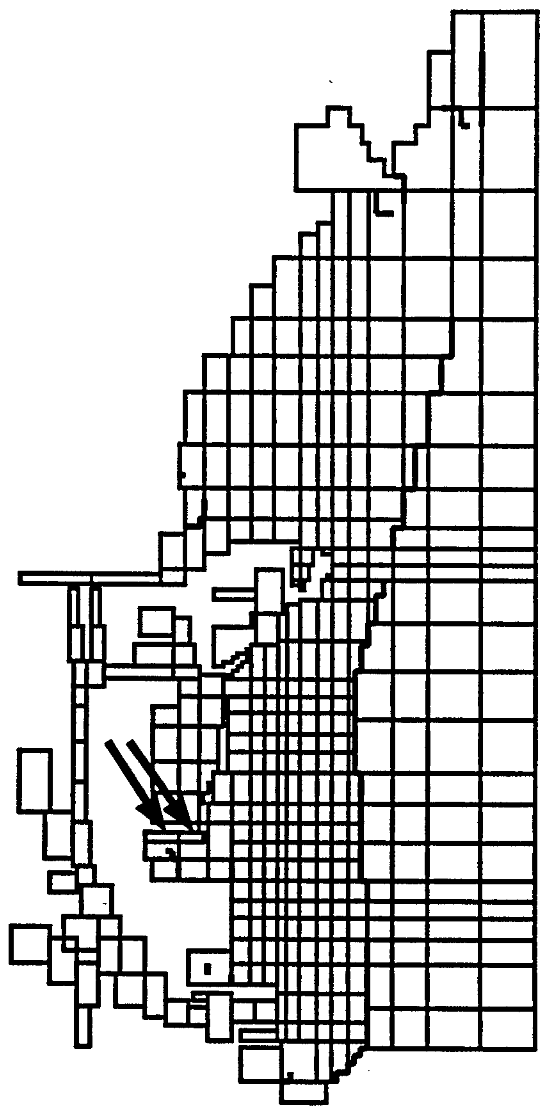


Plate 12

SAN PEDRO BAY - EXISTX

Water Quality Model Grid



SAN PEDRO BAY - EXISTX

Water Quality Model Grid Overlaid

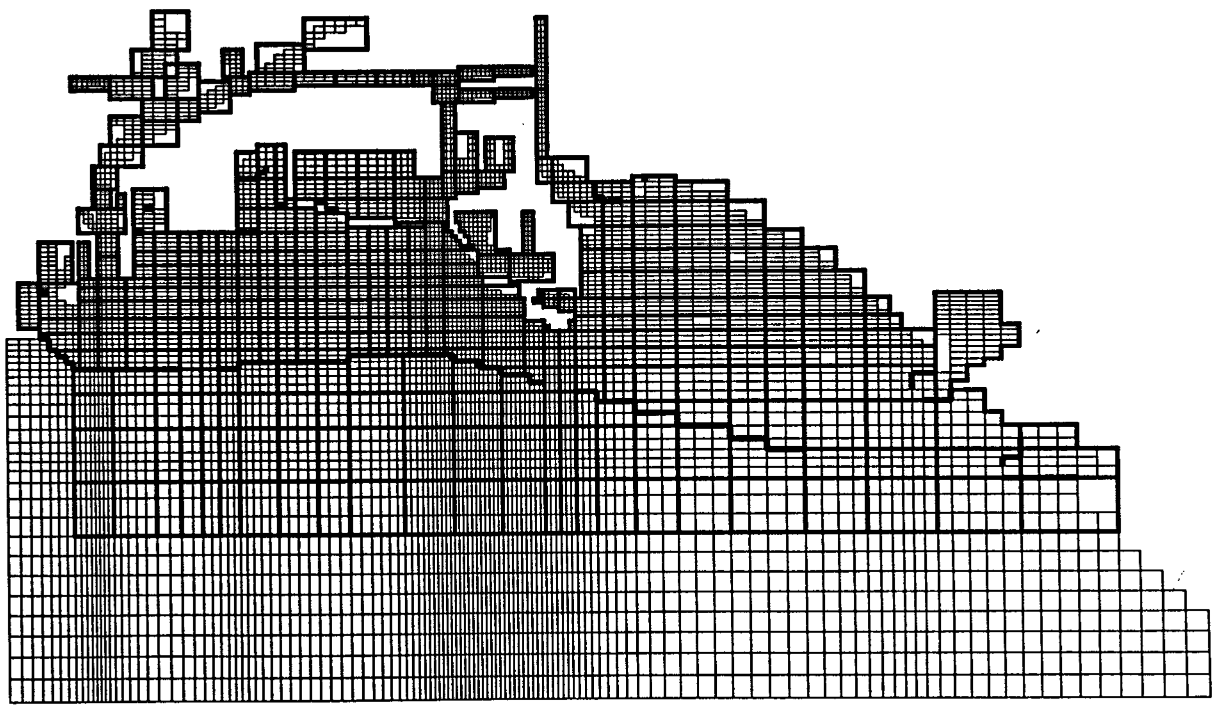
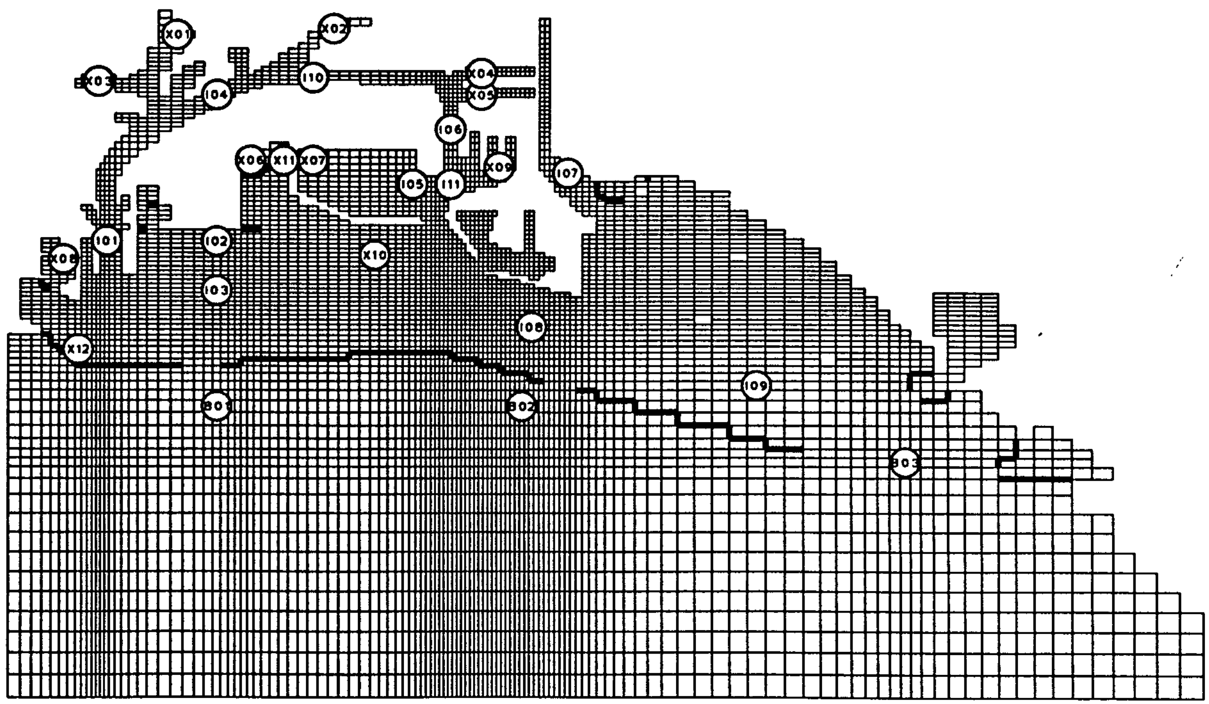


Plate 14

SAN PEDRO BAY - BASE

Water Quality Stations



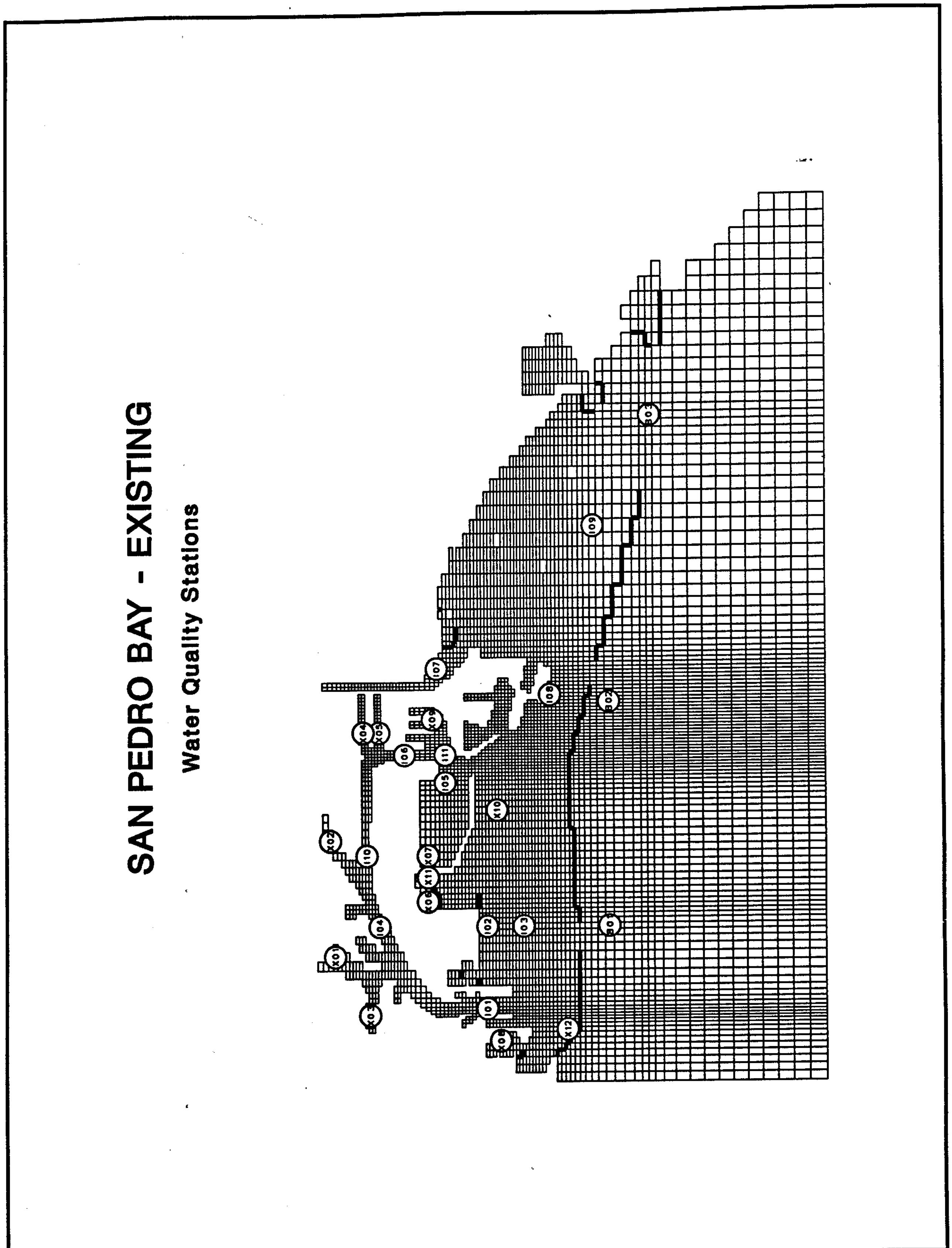
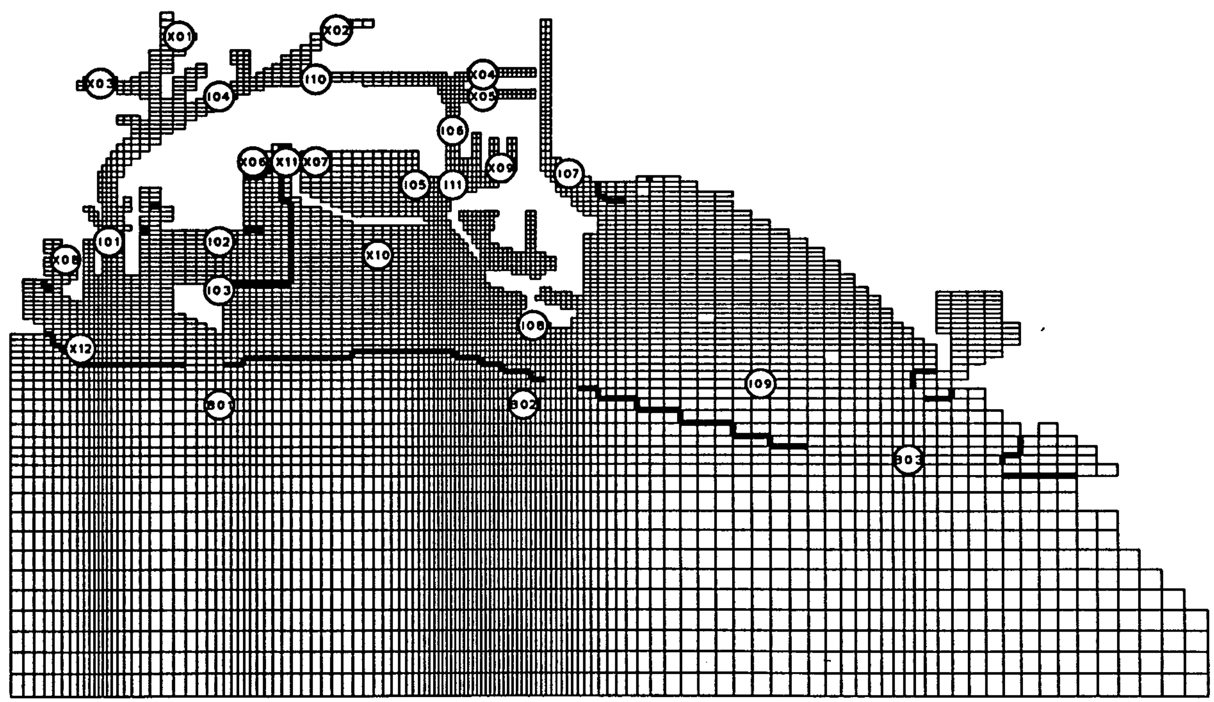


Plate 16

SAN PEDRO BAY - POLA STAGE 1

Water Quality Stations



SAN PEDRO BAY - POLA STAGE 2

Water Quality Stations

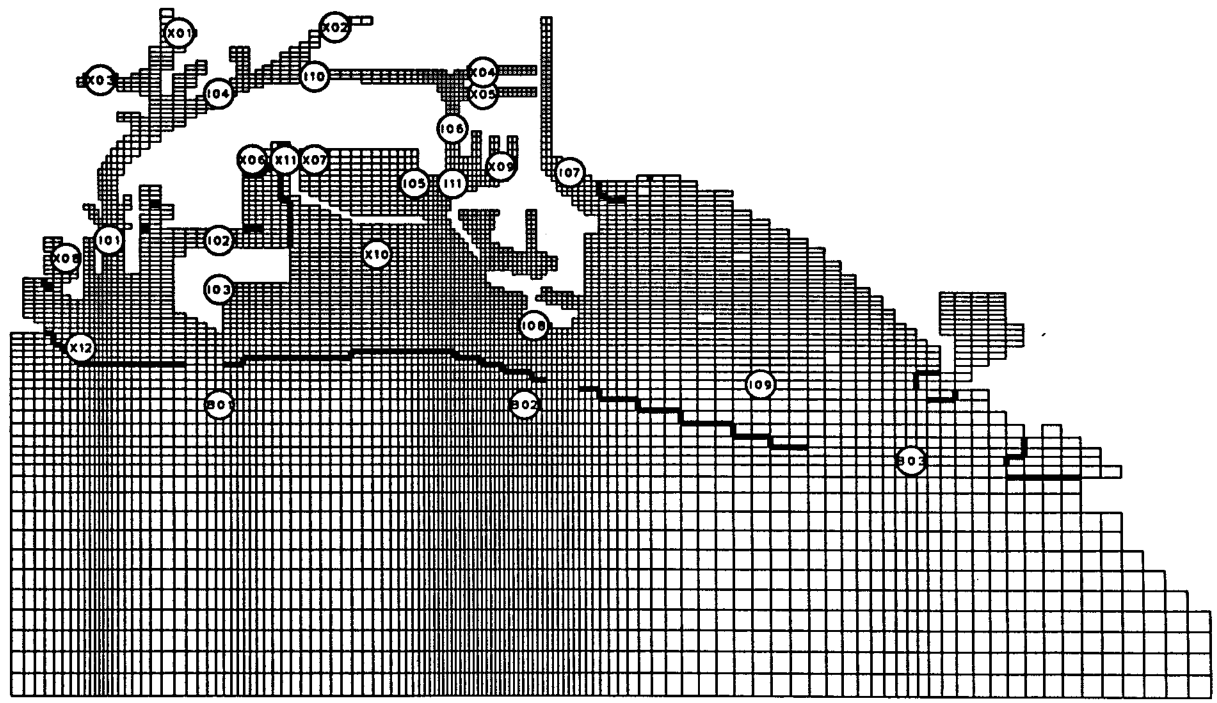


Plate 18

Appendix A
Shade and Flush Plots

Plate	Plot
A1	Existing, Shade Plot, 5 Days
A2	POLA Stage 1, Shade Plot, 5 Days
A3	POLA Stage 2, Shade Plot, 5 Days
A4	Existing, Shade Plot, 15 Days
A5	POLA Stage 1, Shade Plot, 15 Days
A6	POLA Stage 2, Shade Plot, 15 Days
A7	Existing, Shade Plot, 25 Days
A8	POLA Stage 1, Shade Plot, 25 Days
A9	POLA Stage 2, Shade Plot, 25 Days
A10	Flushing Experiment, East of Access Causeway
A11	Existing, Shade Plot, X-11, 2.5 Days
A12	POLA Stage 2, Shade Plot, X-11, 2.5 Days

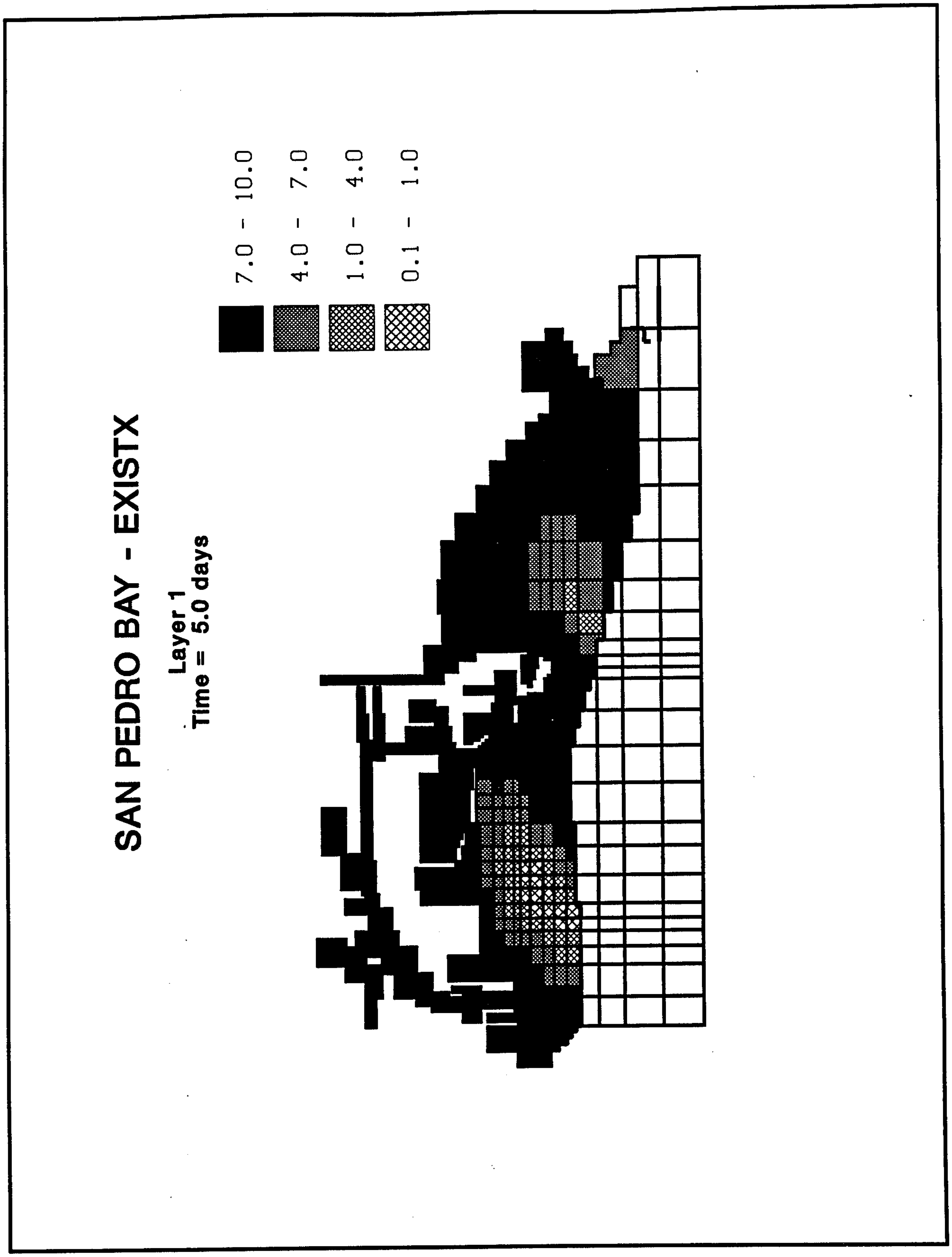

SAN PEDRO BAY - EXISTX
Layer 1
Time = 5.0 days
7.0 - 10.0
4.0 - 7.0
1.0 - 4.0
0.1 - 1.0

Plate A1

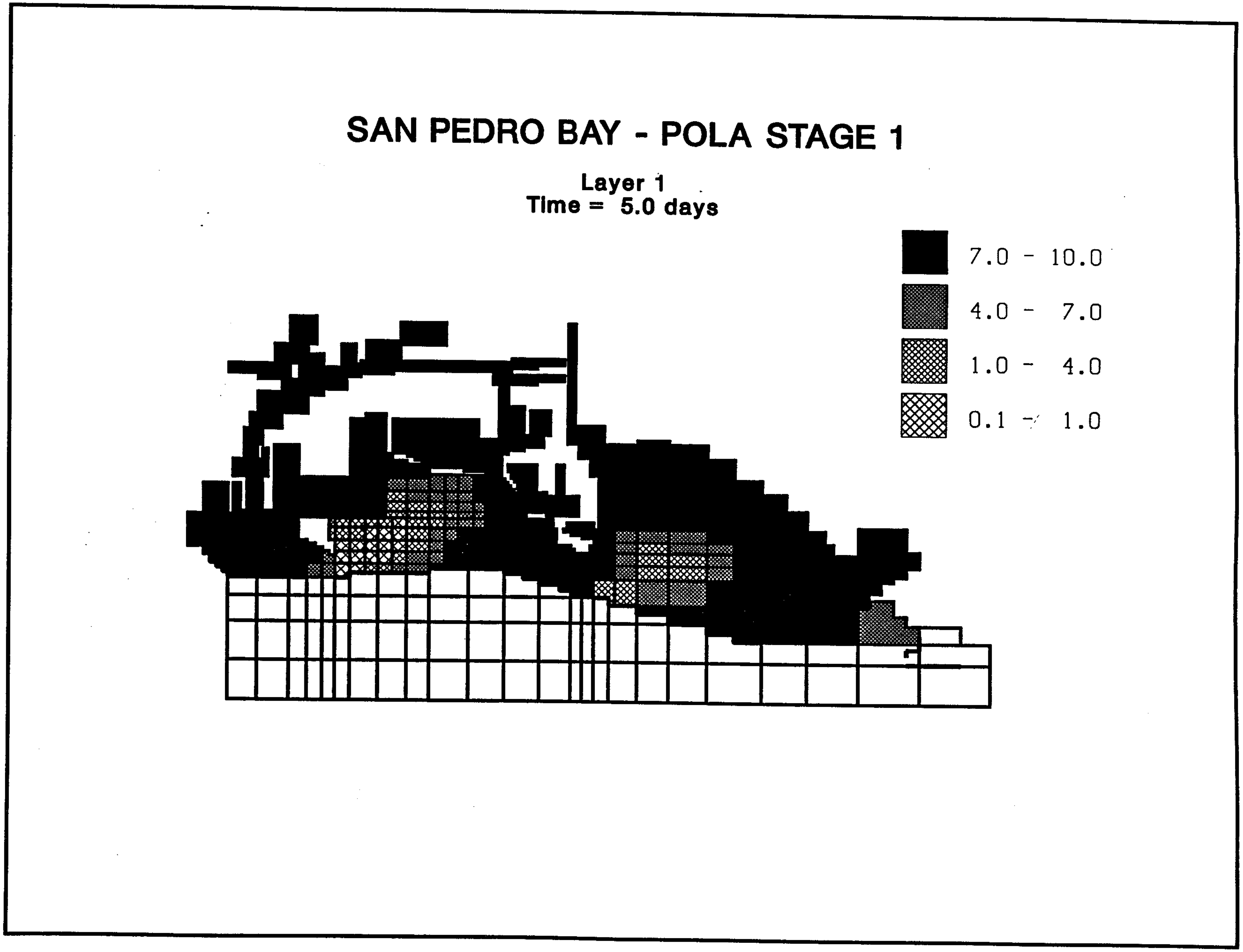

SAN PEDRO BAY - POLA STAGE 1
Layer 1
Time = 5.0 days
7.0 - 10.0
4.0 - 7.0
1.0 - 4.0
0.1 - 1.0

Plate A2

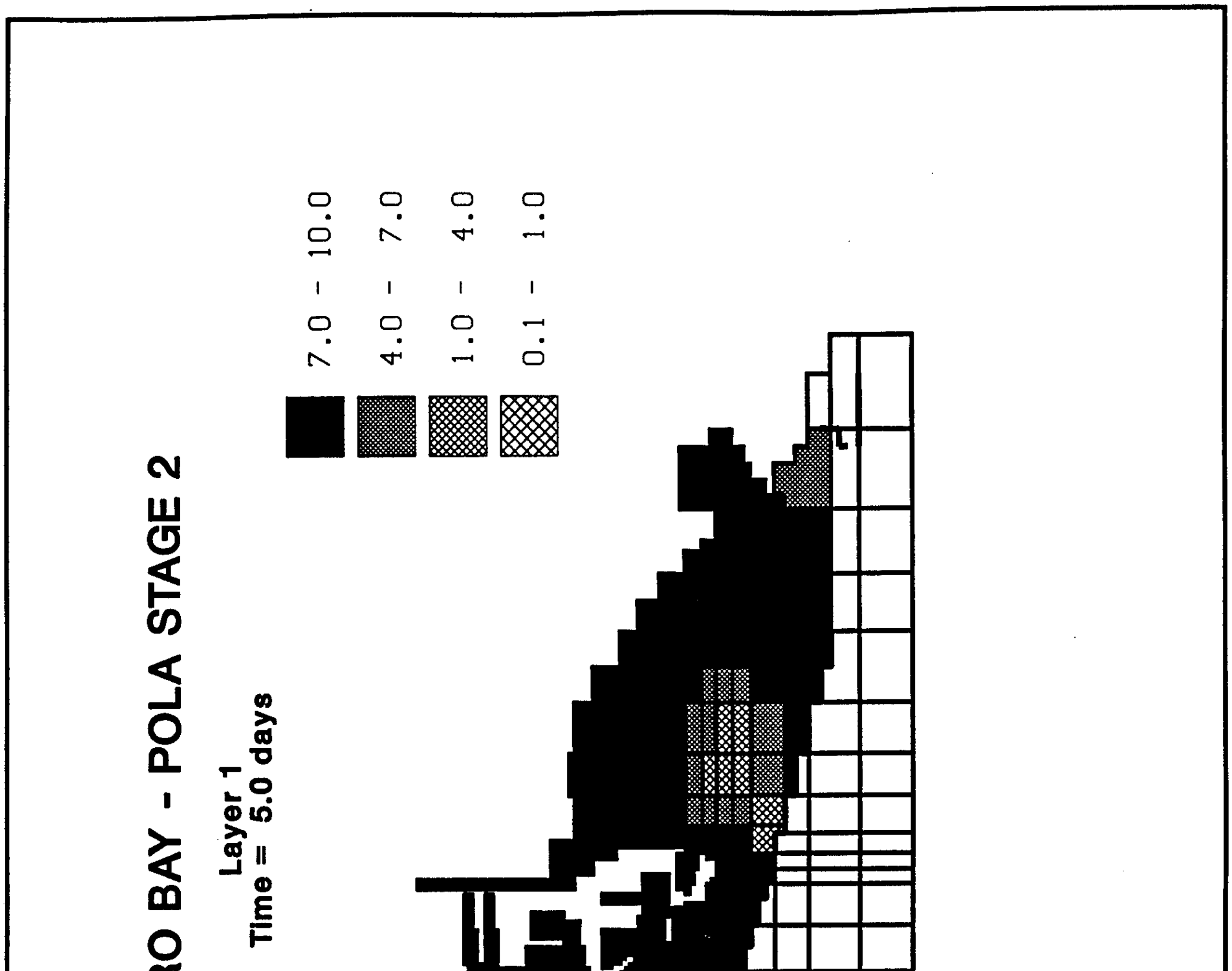
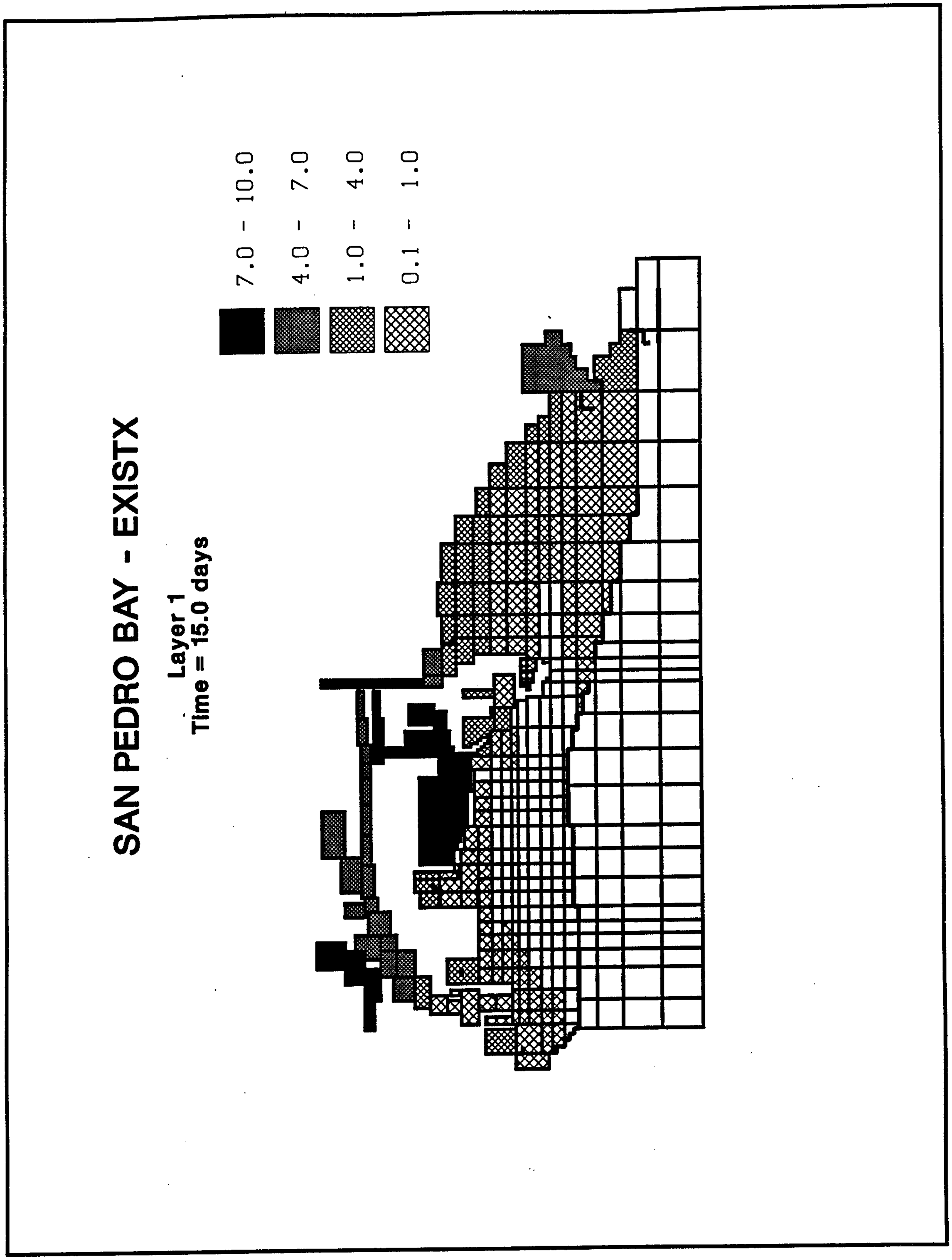
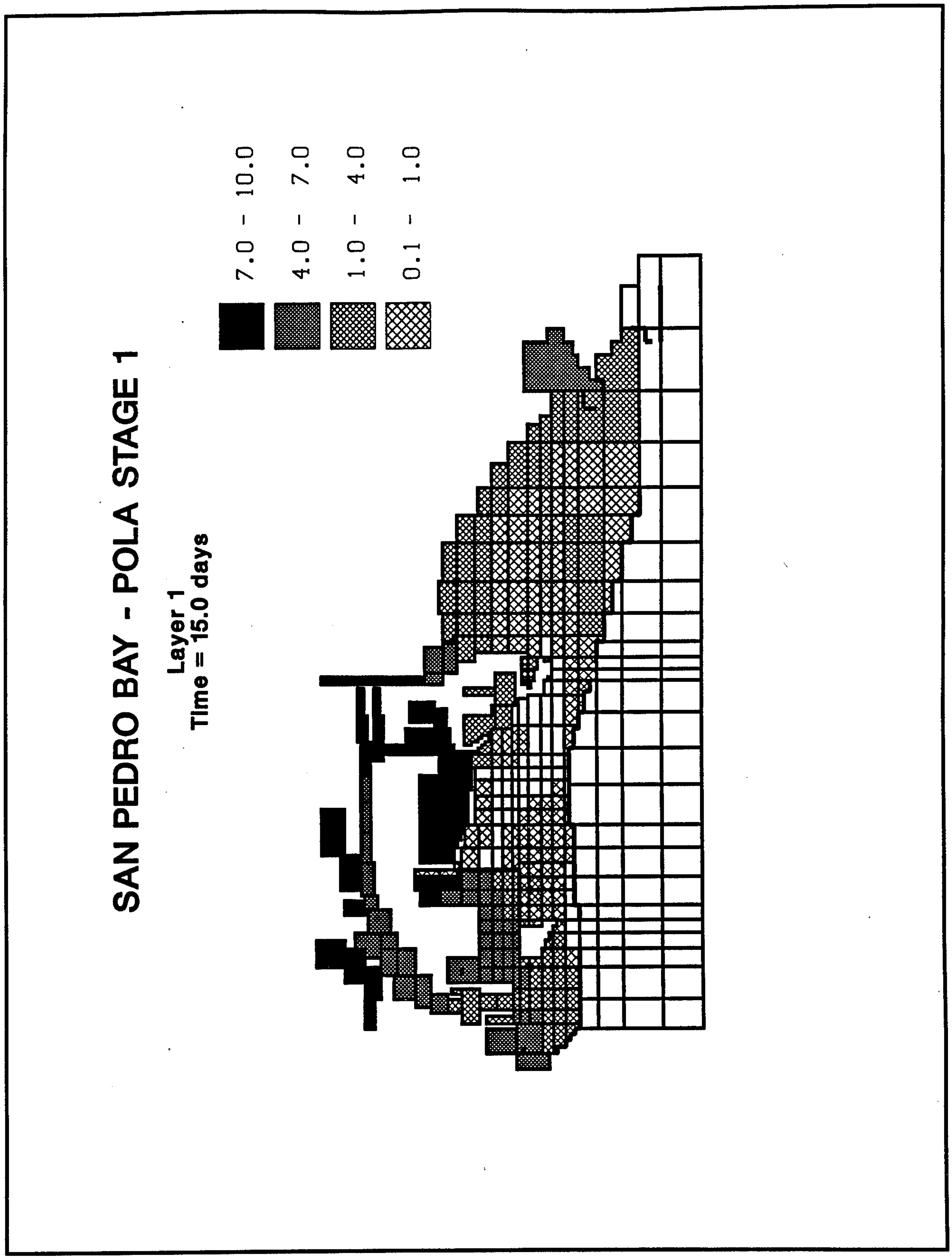

SAN PEDRO BAY - POLA STAGE 2
Layer 1
Time = 5.0 days
7.0 - 10.0
4.0 - 7.0
1.0 - 4.0
0.1 - 1.0

Plate A3



SAN PEDRO BAY - EXISTX
Layer 1
Time = 15.0 days
7.0 - 10.0
4.0 - 7.0
1.0 - 4.0
0.1 - 1.0

Plate A4



SAN PEDRO BAY - POLA STAGE 1
Layer 1
Time = 15.0 days
7.0 - 10.0
4.0 - 7.0
1.0 - 4.0
0.1 - 1.0

SAN PEDRO BAY - POLA STAGE 2

Layer 1
Time = 15.0 days

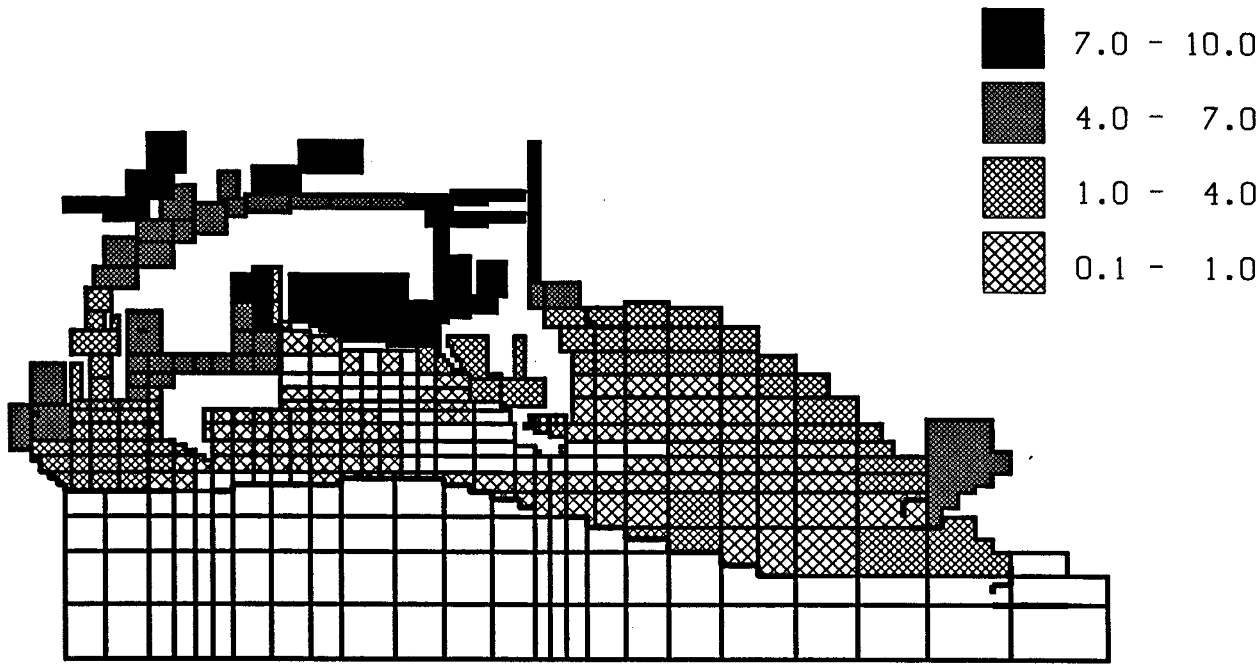


Plate A6

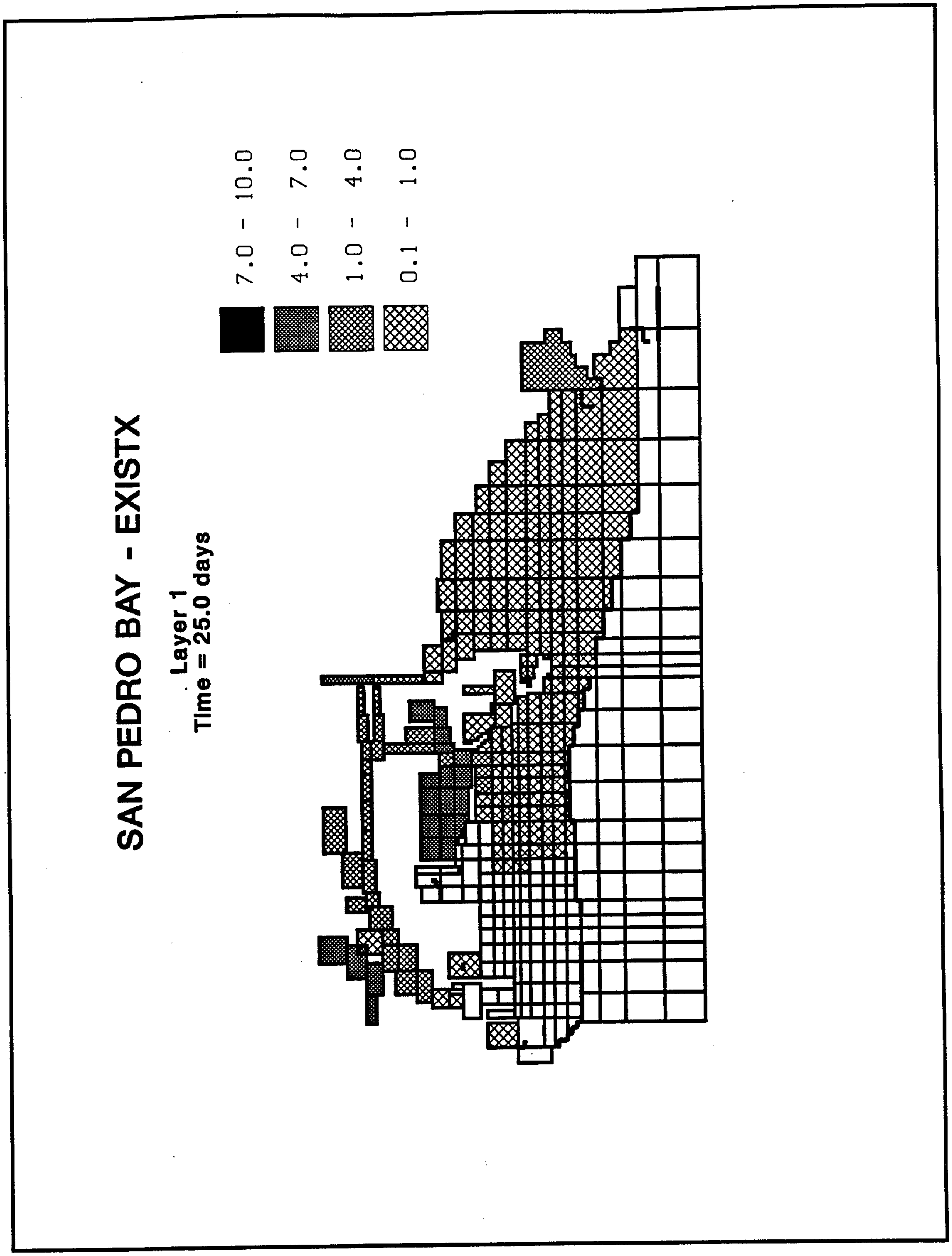

SAN PEDRO BAY - EXISTX
Layer 1
Time = 25.0 days
7.0 - 10.0
4.0 - 7.0
1.0 - 4.0
0.1 - 1.0

Plate A7

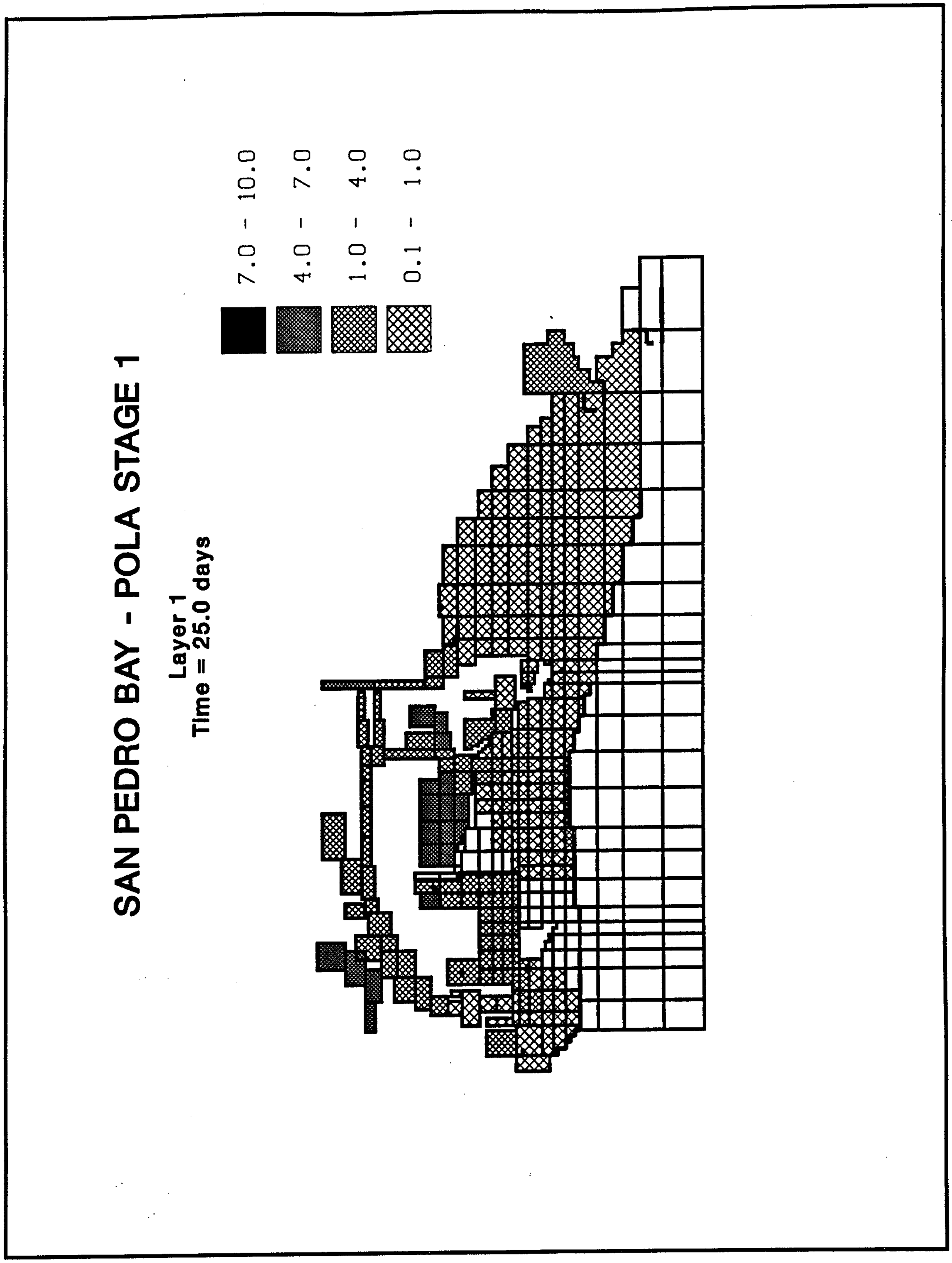
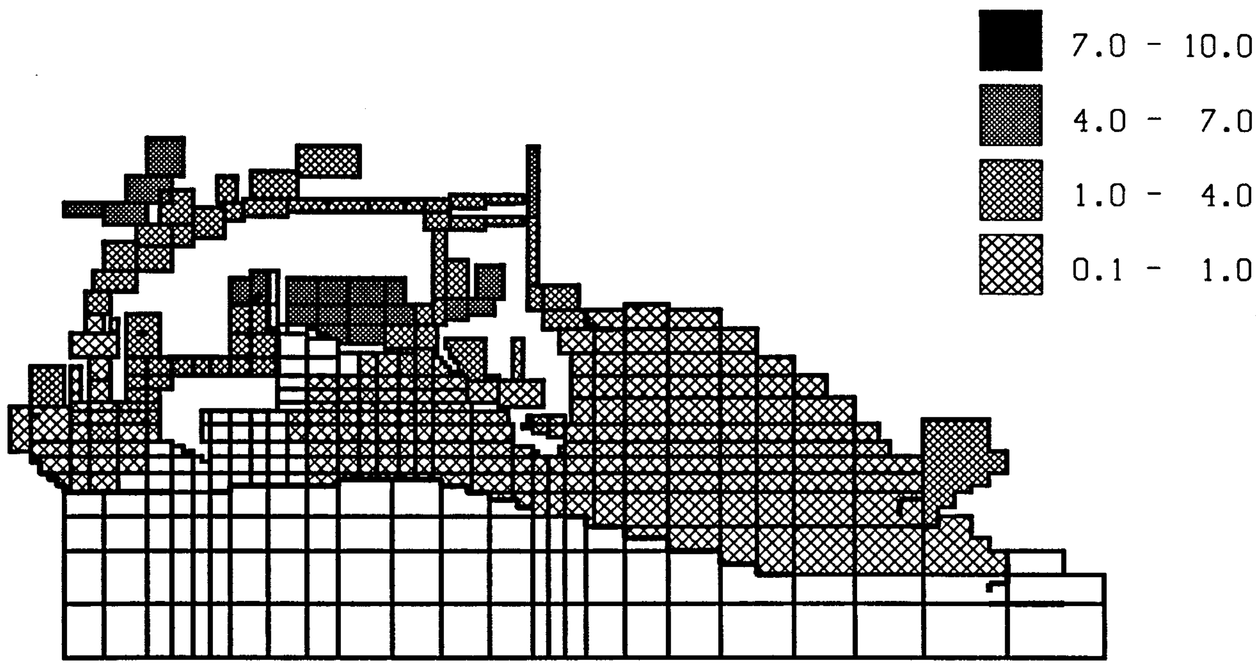
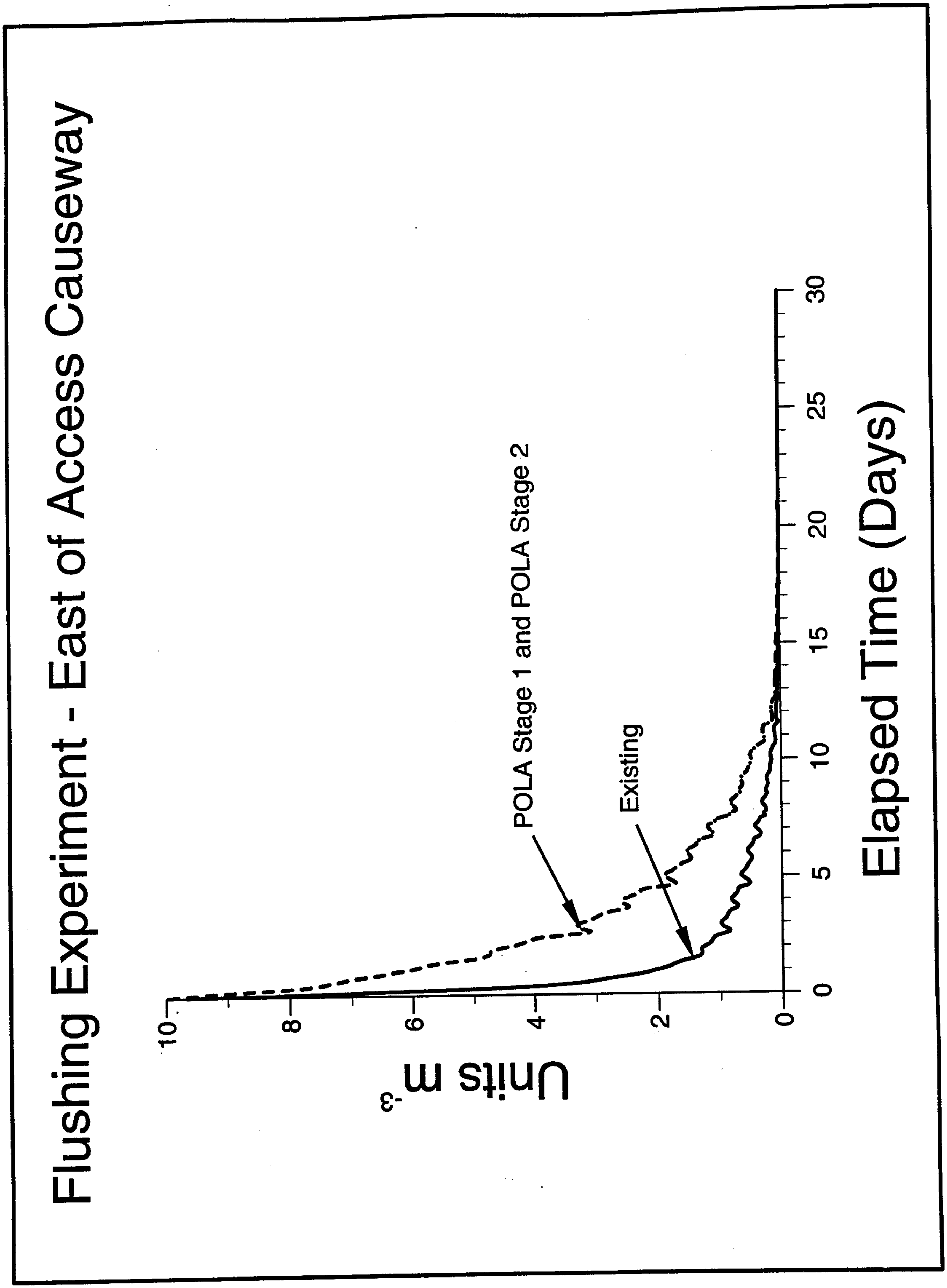

SAN PEDRO BAY - POLA STAGE 1
Layer 1
Time = 25.0 days
7.0 - 10.0
4.0 - 7.0
1.0 - 4.0
0.1 - 1.0

Plate A8

SAN PEDRO BAY - POLA STAGE 2

Layer 1
Time = 25.0 days





Flushing Experiment - East of Access Causeway

Plate A10

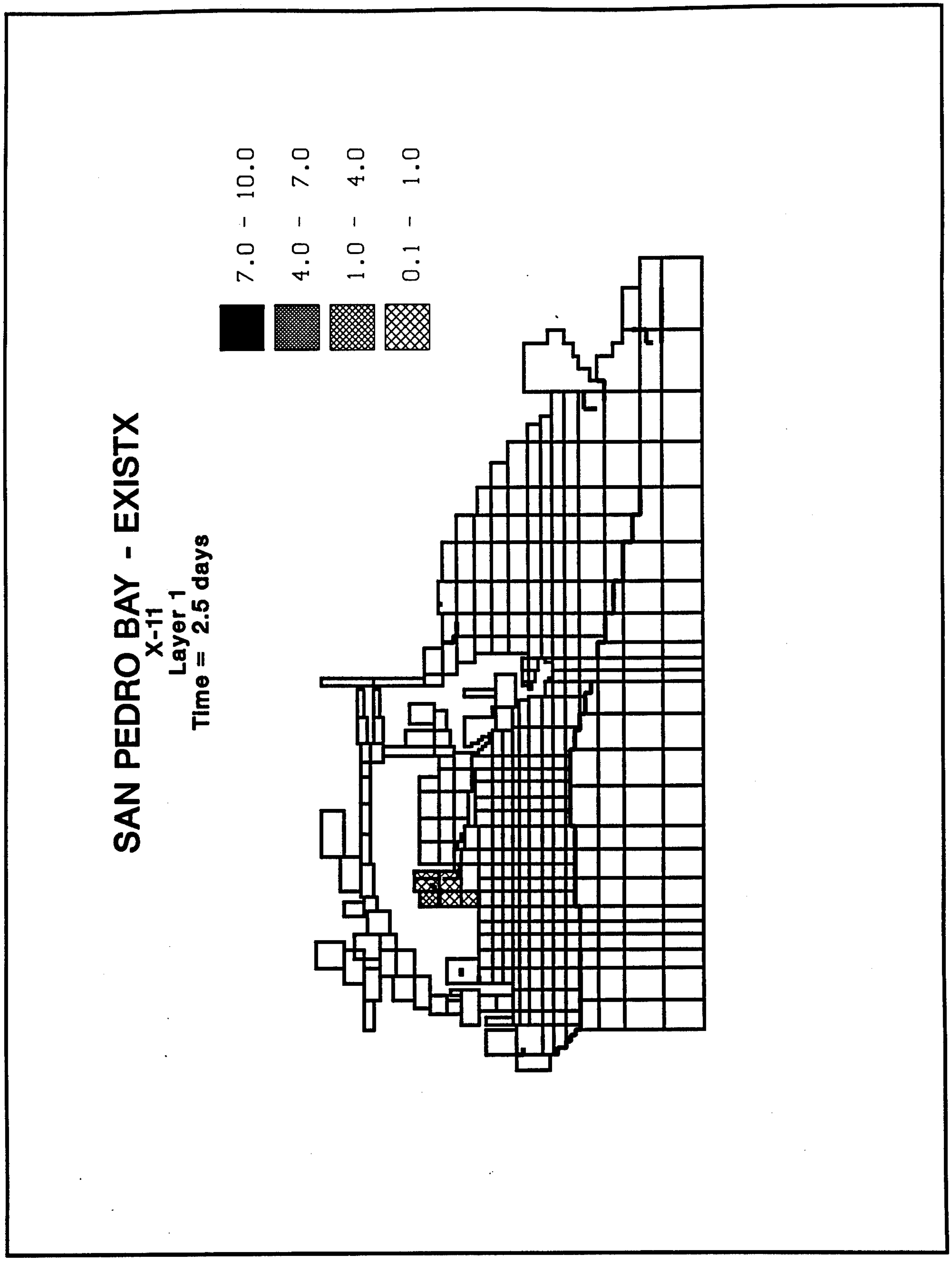

SAN PEDRO BAY - EXISTX
X-11
Layer 1
Time = 2.5 days
7.0 - 10.0
4.0 - 7.0
1.0 - 4.0
0.1 - 1.0

Plate A11

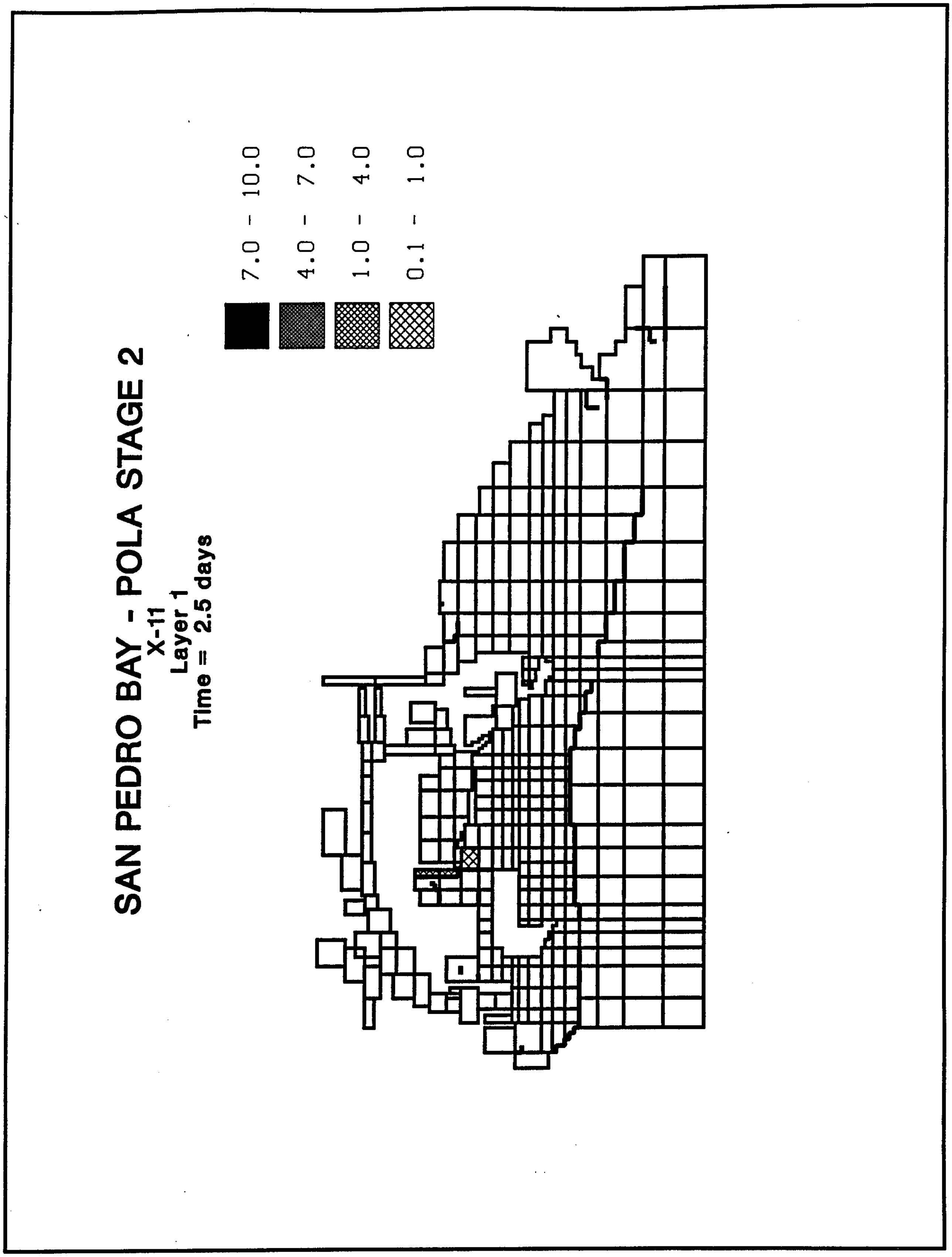

SAN PEDRO BAY - POLA STAGE 2
X-11
Layer 1
Time = 2.5 days
7.0 - 10.0
4.0 - 7.0
1.0 - 4.0
0.1 - 1.0

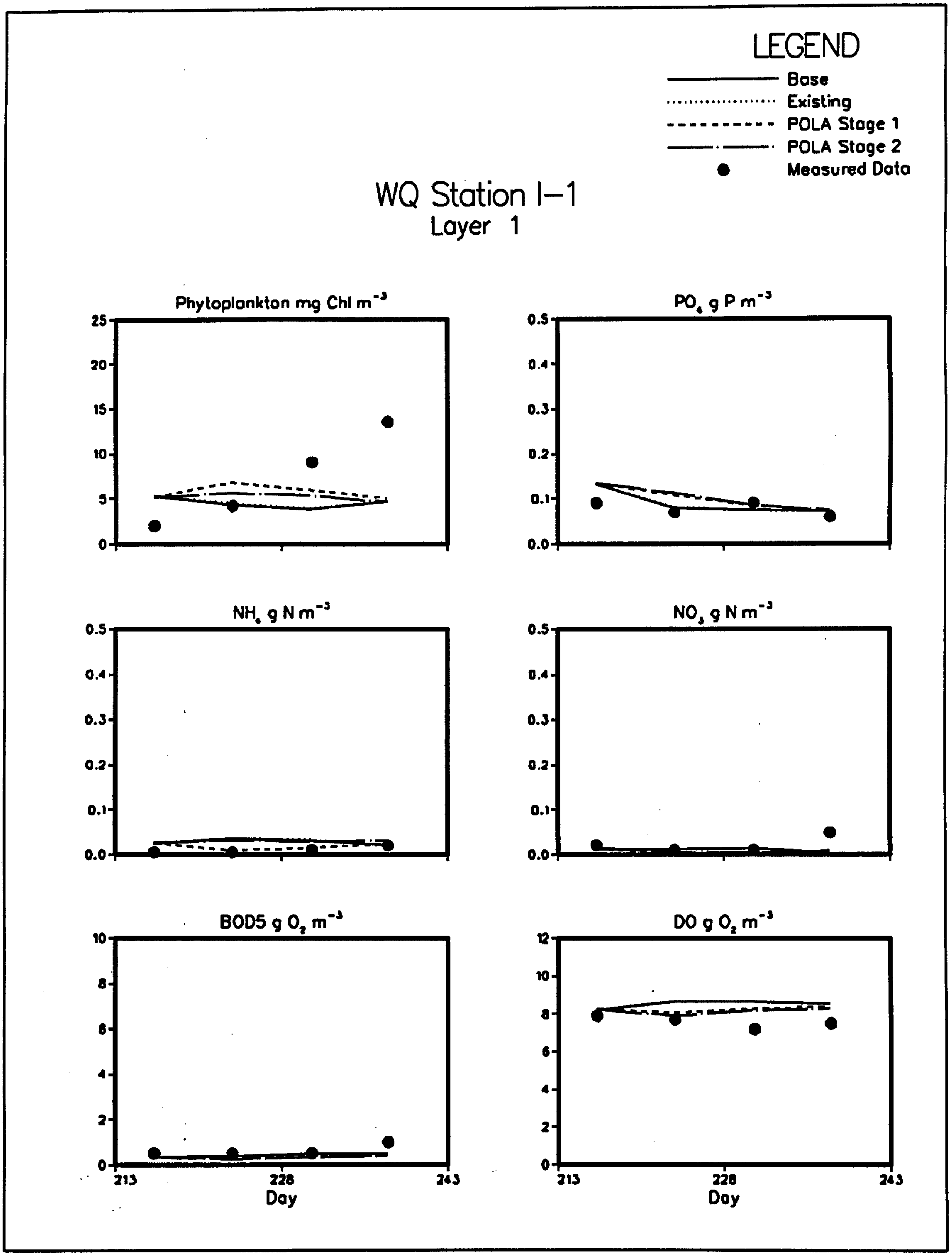
Plate A12

Appendix B
Time Series Plots

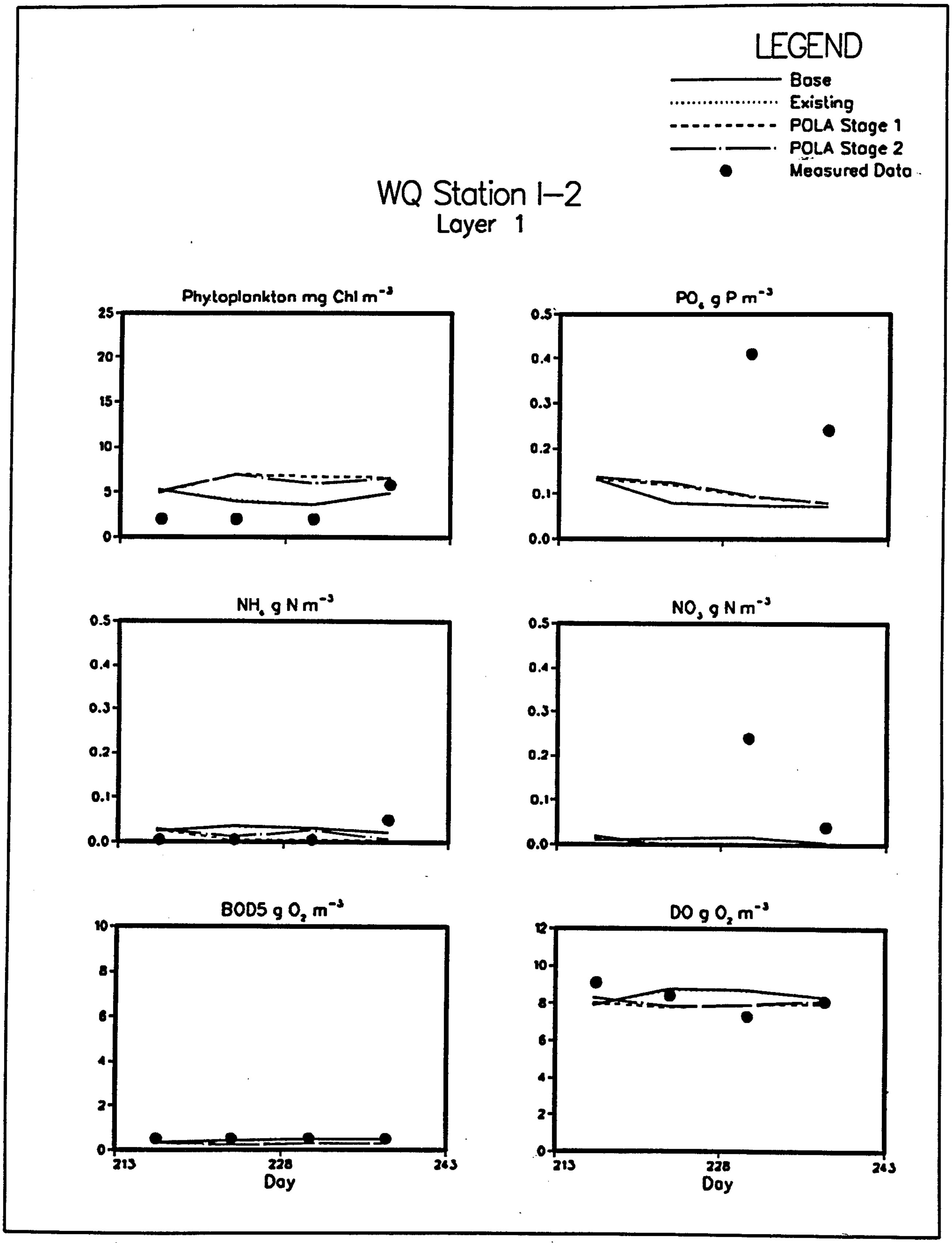
Plate	Plot
B1	Station I-01, Layer 1
B2	Station I-02, Layer 1
B3	Station I-03, Layer 1
B4	Station I-04, Layer 1
B5	Station I-05, Layer 1
B6	Station I-06, Layer 1
B7	Station I-07, Layer 1
B8	Station I-08, Layer 1
B9	Station I-09, Layer 1
B10	Station I-10, Layer 1
B11	Station I-11, Layer 1
B12	Station B-01, Layer 1
B13	Station B-02, Layer 1
B14	Station B-03, Layer 1
B15	Station X-01, Layer 1
B16	Station X-02, Layer 1
B17	Station X-03, Layer 1
B18	Station X-04, Layer 1
B19	Station X-05, Layer 1
B20	Station X-06, Layer 1
B21	Station X-07, Layer 1
B22	Station X-08, Layer 1
B23	Station X-09, Layer 1
B24	Station X-10, Layer 1
B25	Station X-11, Layer 1
B26	Station X-12, Layer 1
B27	Station I–01, Layer 5
B28	Station I–02, Layer 5
B29	Station I–03, Layer 5
B30	Station I–04, Layer 5
B31	Station I–05, Layer 5
B32	Station I–06, Layer 5
B33	Station I–07, Layer 5

(Continued)

Concluded	
Plate	**Plot**
B34	Station I-08, Layer 5
B35	Station I-09, Layer 5
B36	Station I-10, Layer 5
B37	Station I-11, Layer 5
B38	Station B-01, Layer 5
B39	Station B-02, Layer 5
B40	Station B-03, Layer 5
B41	Station X-01, Layer 5
B42	Station X-02, Layer 5
B43	Station X-03, Layer 5
B44	Station X-04, Layer 5
B45	Station X-05, Layer 5
B46	Station X-06, Layer 5
B47	Station X-07, Layer 5
B48	Station X-08, Layer 5
B49	Station X-09, Layer 5
B50	Station X-10, Layer 5
B51	Station X-11, Layer 5
B52	Station X-12, Layer 5



LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
Measured Data
WQ Station I-1
Layer 1
Phytoplankton mg Chl m-3
PO4 g P m-3
NH4 g N m-3
NO3 g N m-3
BOD5 g O2 m-3
DO g O2 m-3
Day
213
228
243



LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
Measured Data
WQ Station I–2
Layer 1
Phytoplankton mg Chl m⁻³
PO₄ g P m⁻³
NH₄ g N m⁻³
NO₃ g N m⁻³
BOD5 g O₂ m⁻³
DO g O₂ m⁻³
Day

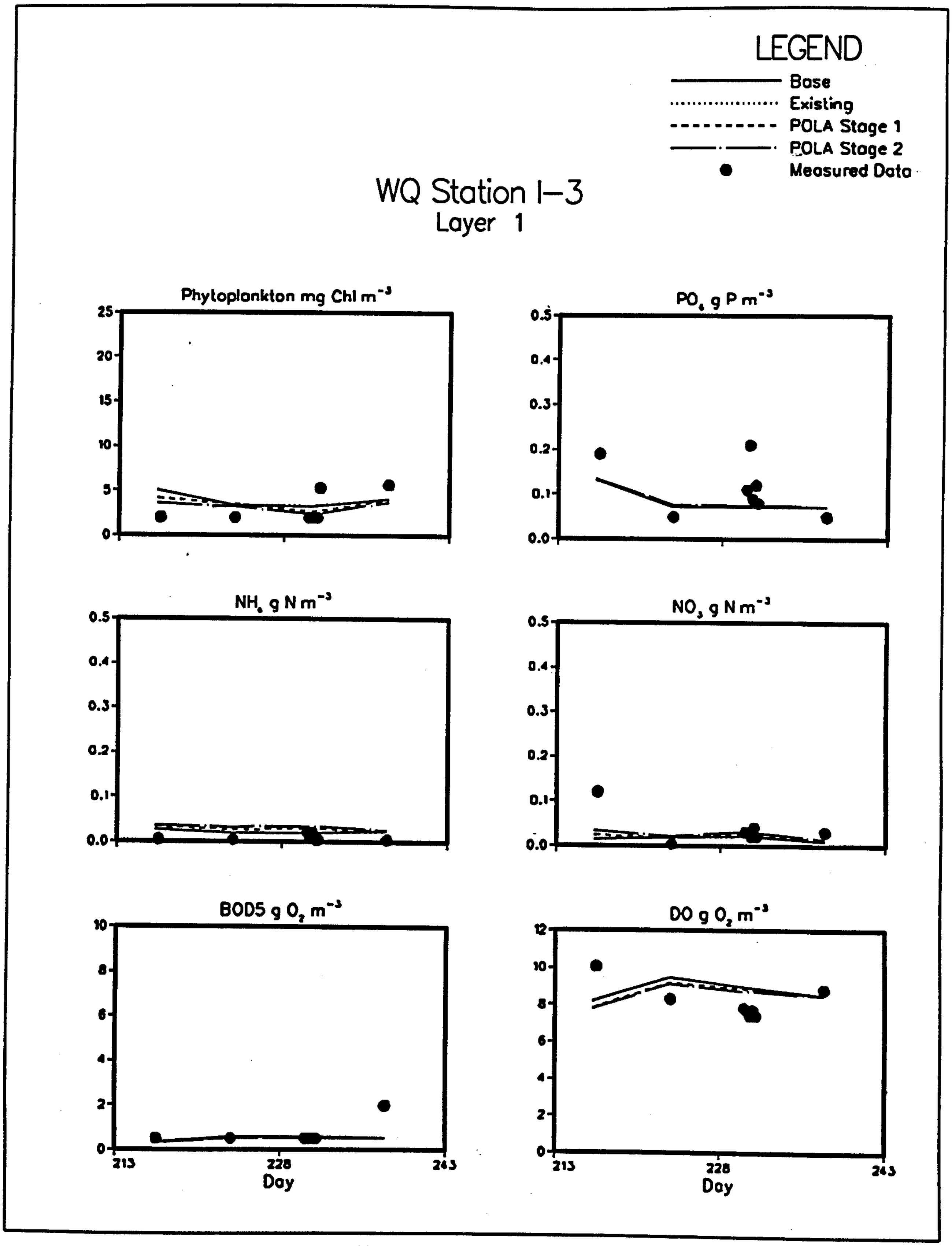
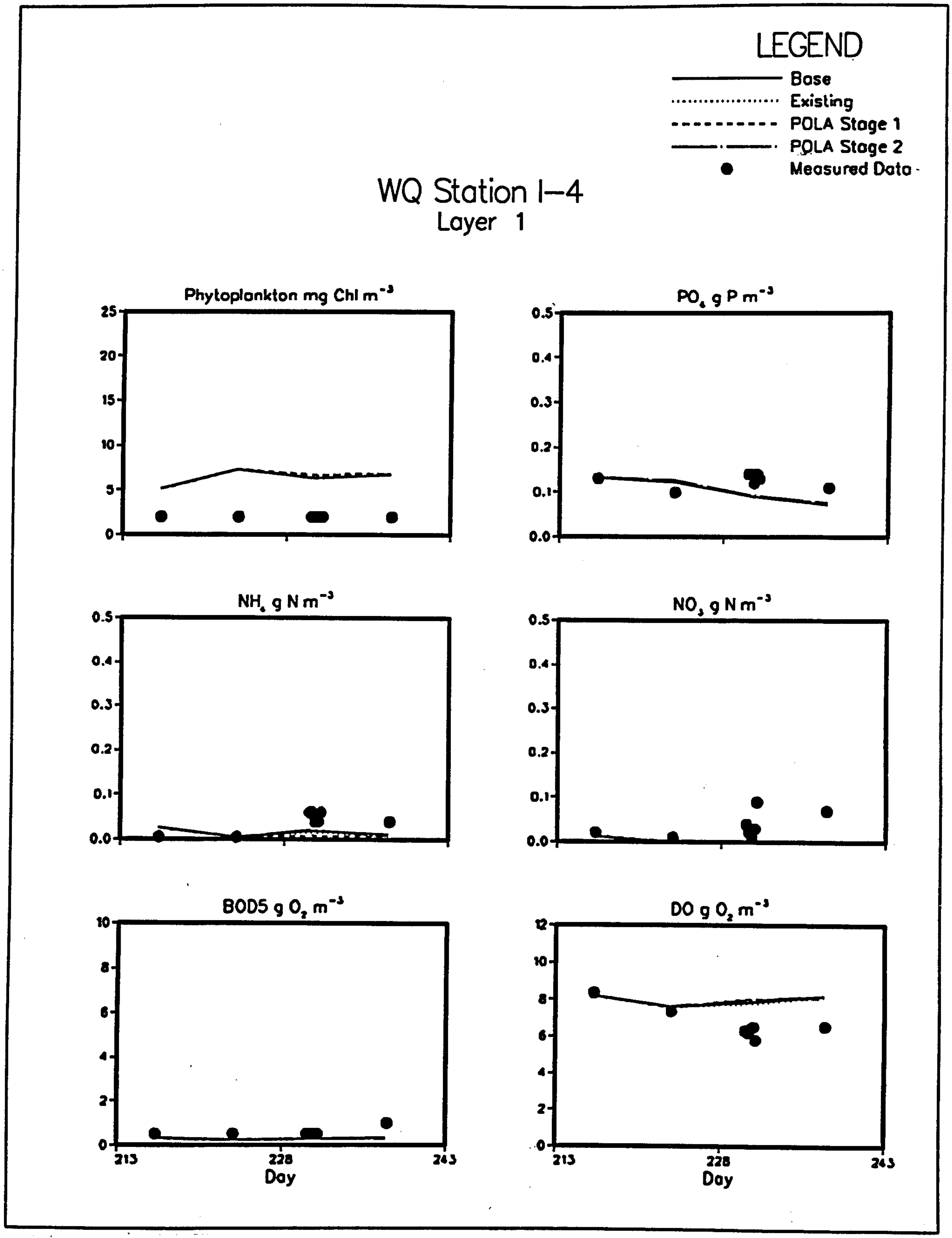

LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
Measured Data
WQ Station I-3
Layer 1
Phytoplankton mg Chl m^-3
PO4 g P m^-3
NH4 g N m^-3
NO3 g N m^-3
BOD5 g O2 m^-3
DO g O2 m^-3
213
228
243
Day

Plate B3



LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
Measured Data
WQ Station I–4
Layer 1
Phytoplankton mg Chl m-3
PO4 g P m-3
NH4 g N m-3
NO3 g N m-3
BOD5 g O2 m-3
DO g O2 m-3
Day
Day

Plate B4

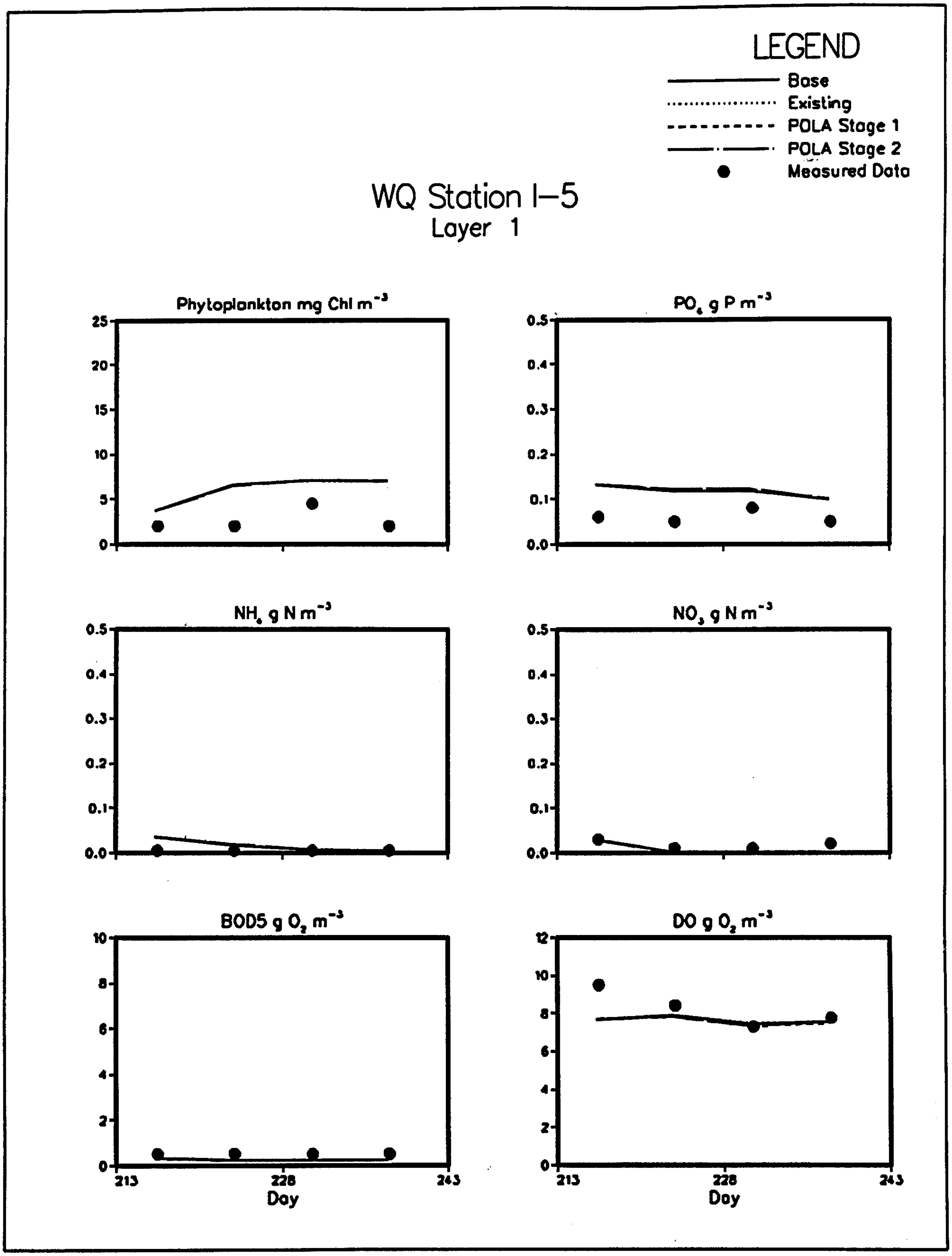
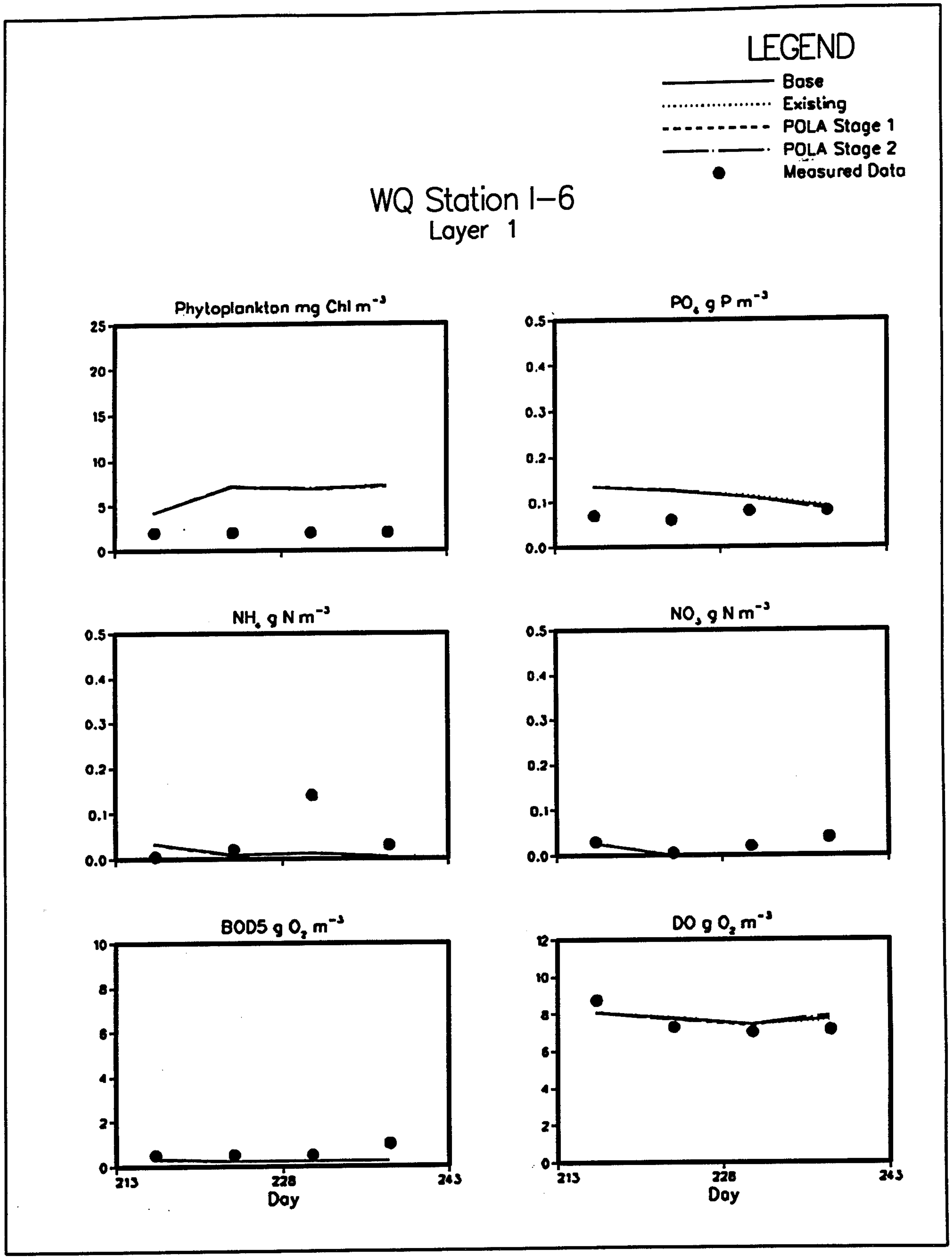
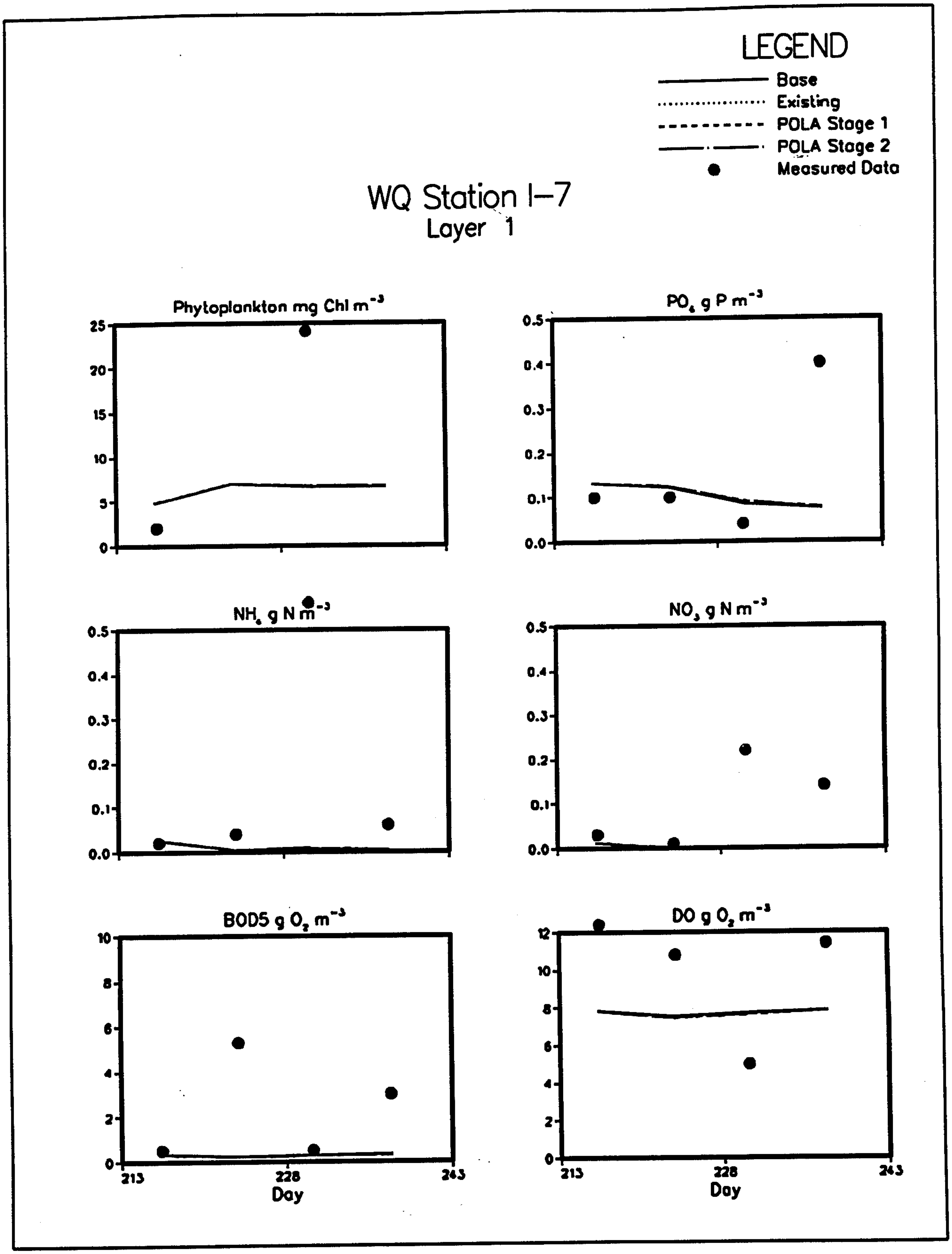
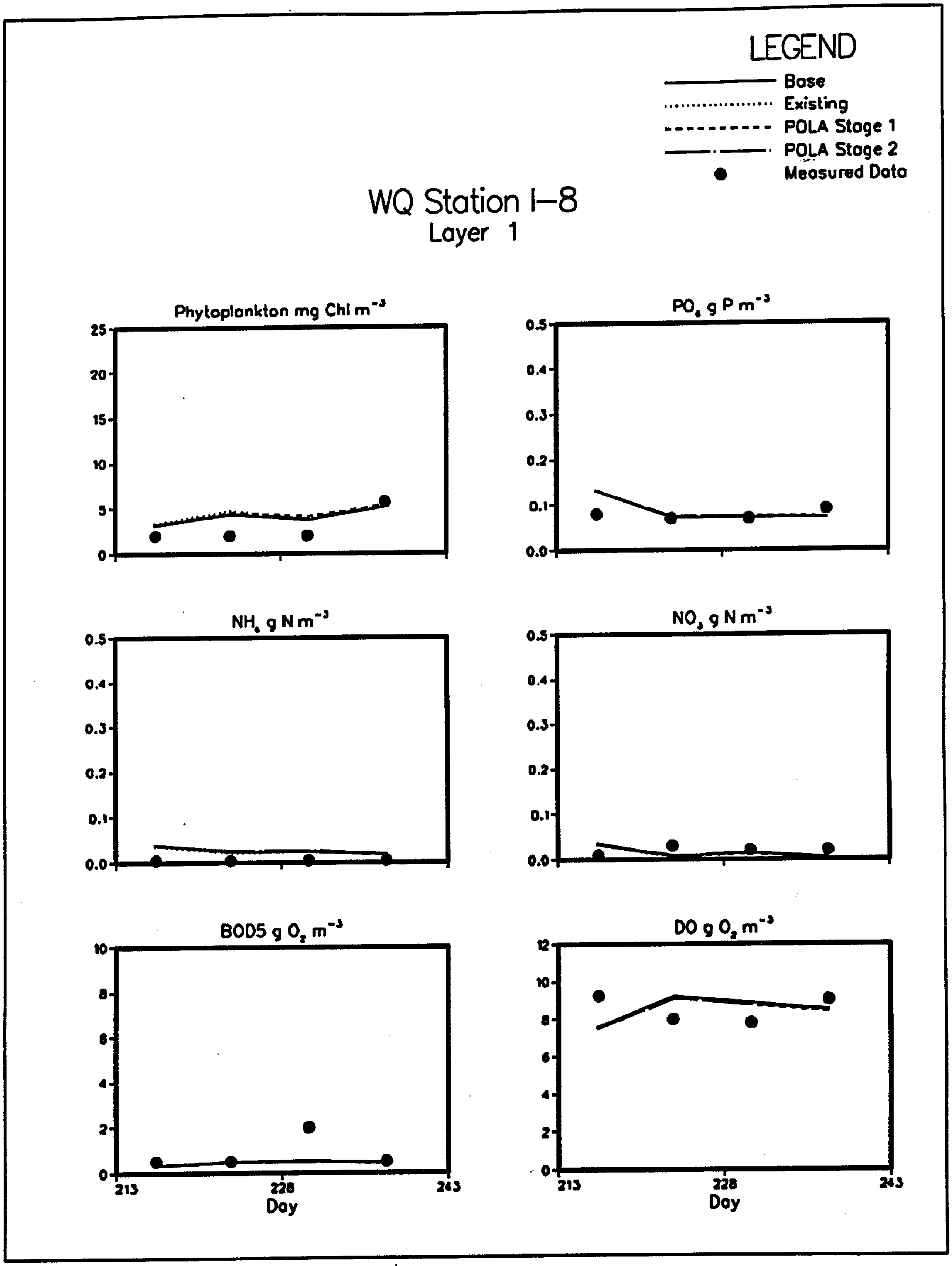

LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
Measured Data
WQ Station I-5
Layer 1
Phytoplankton mg Chl m^-3
PO4 g P m^-3
NH4 g N m^-3
NO3 g N m^-3
BOD5 g O2 m^-3
DO g O2 m^-3
213
228
243
Day

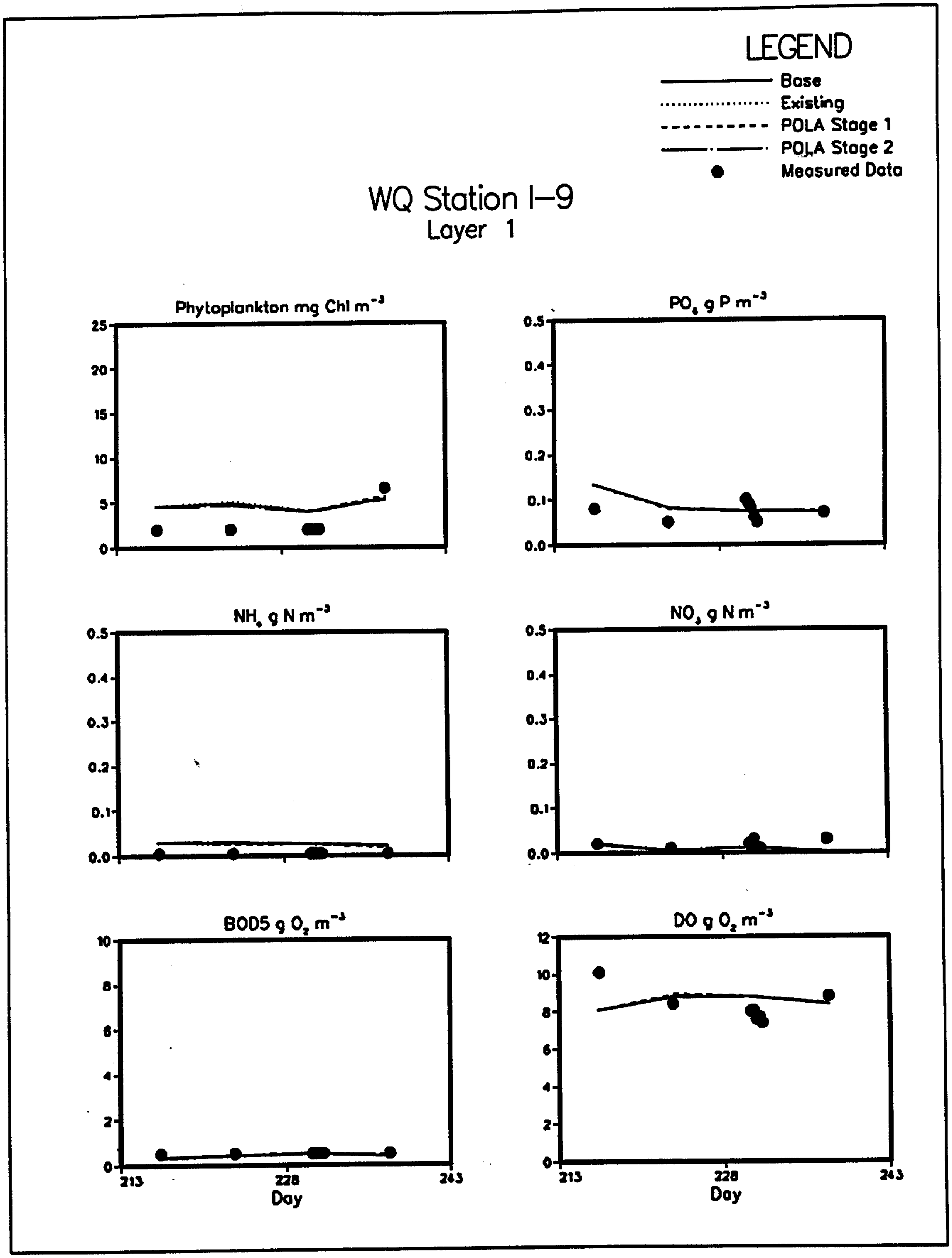
Plate B5


LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
Measured Data
WQ Station I-6
Layer 1
Phytoplankton mg Chl m-3
PO4 g P m-3
NH4 g N m-3
NO3 g N m-3
BOD5 g O2 m-3
DO g O2 m-3
213
228
243
Day



LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
Measured Data
WQ Station I-7
Layer 1
Phytoplankton mg Chl m-3
PO4 g P m-3
NH4 g N m-3
NO3 g N m-3
BOD5 g O2 m-3
DO g O2 m-3
213
228
243
Day


LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
Measured Data
WQ Station I-8
Layer 1
Phytoplankton mg Chl m^-3
PO4 g P m^-3
NH4 g N m^-3
NO3 g N m^-3
BOD5 g O2 m^-3
DO g O2 m^-3
213
228
243
Day



LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
Measured Data
WQ Station I–9
Layer 1
Phytoplankton mg Chl m-3
PO4 g P m-3
NH4 g N m-3
NO3 g N m-3
BOD5 g O2 m-3
DO g O2 m-3
213
228
243
Day

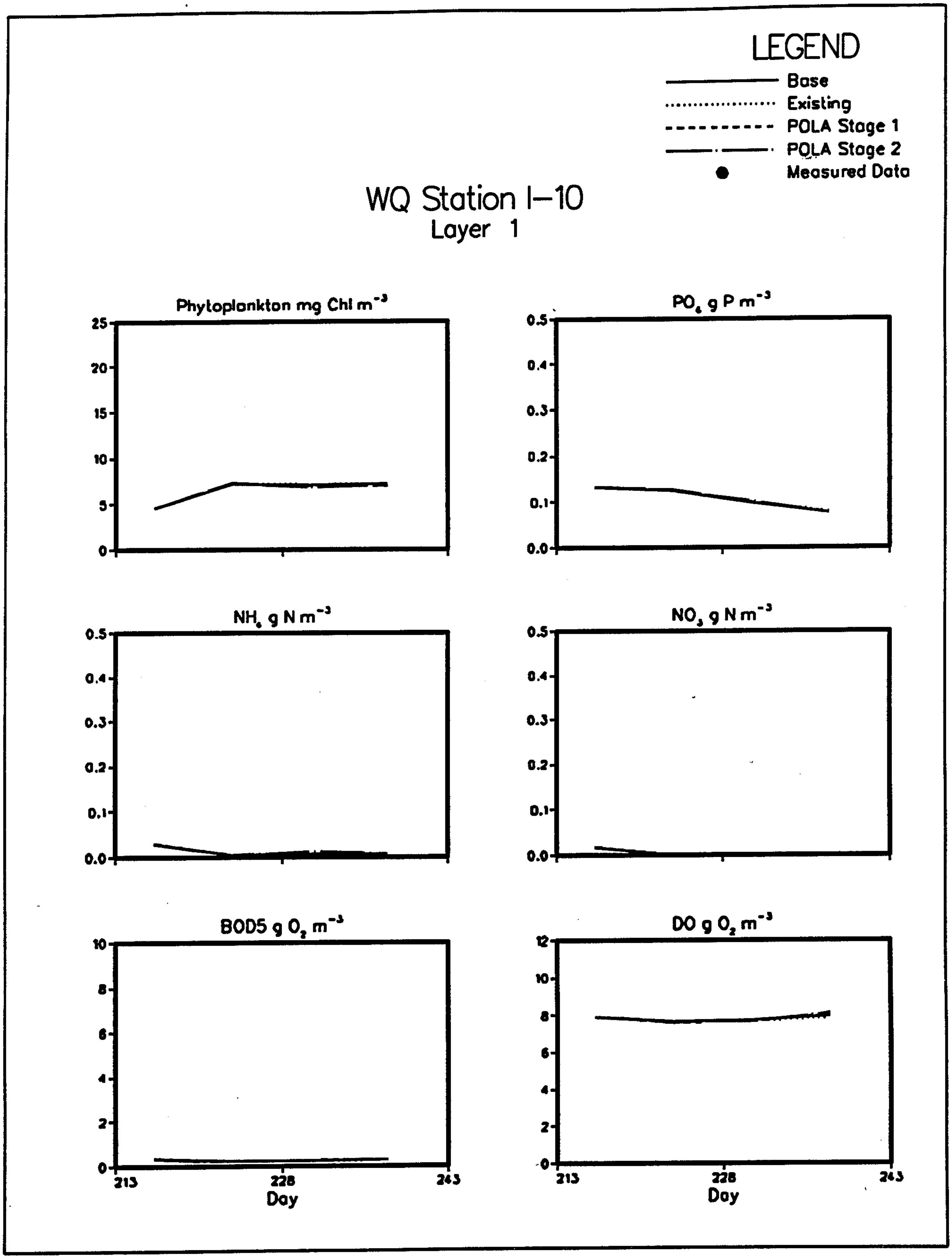

LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
Measured Data
WQ Station I-10
Layer 1
Phytoplankton mg Chl m^-3
PO4 g P m^-3
NH4 g N m^-3
NO3 g N m^-3
BOD5 g O2 m^-3
DO g O2 m^-3
213
228
243
Day

Plate B10

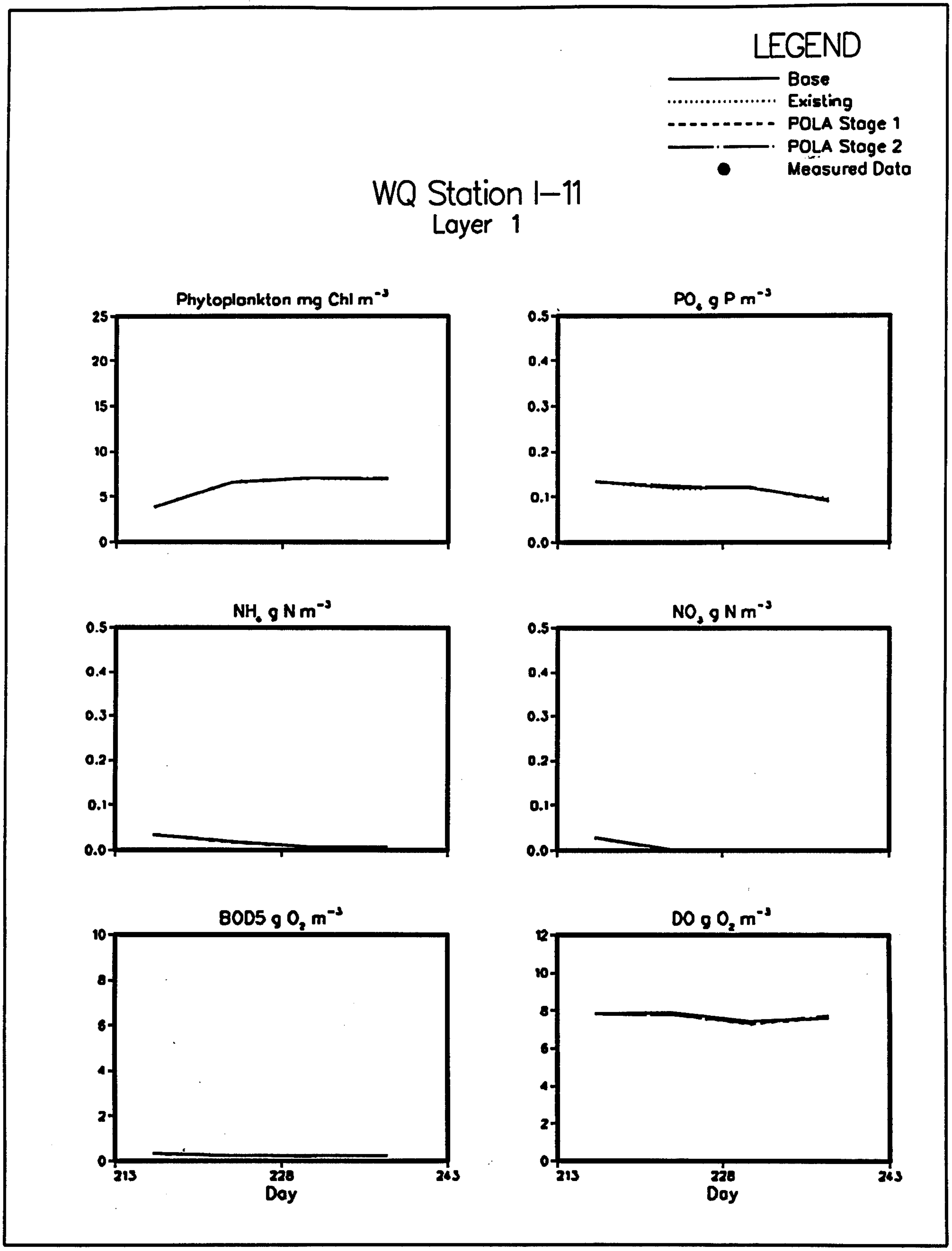
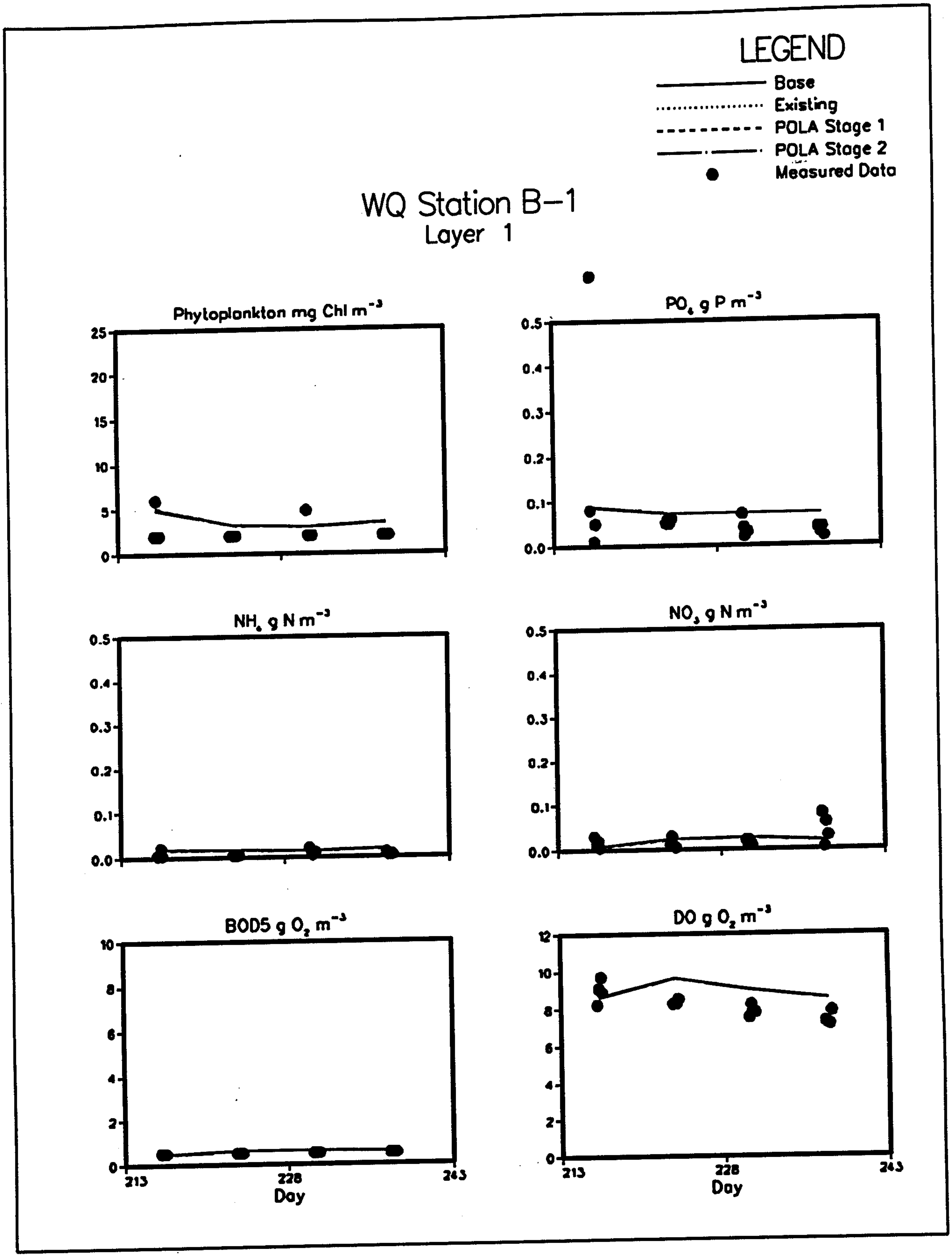
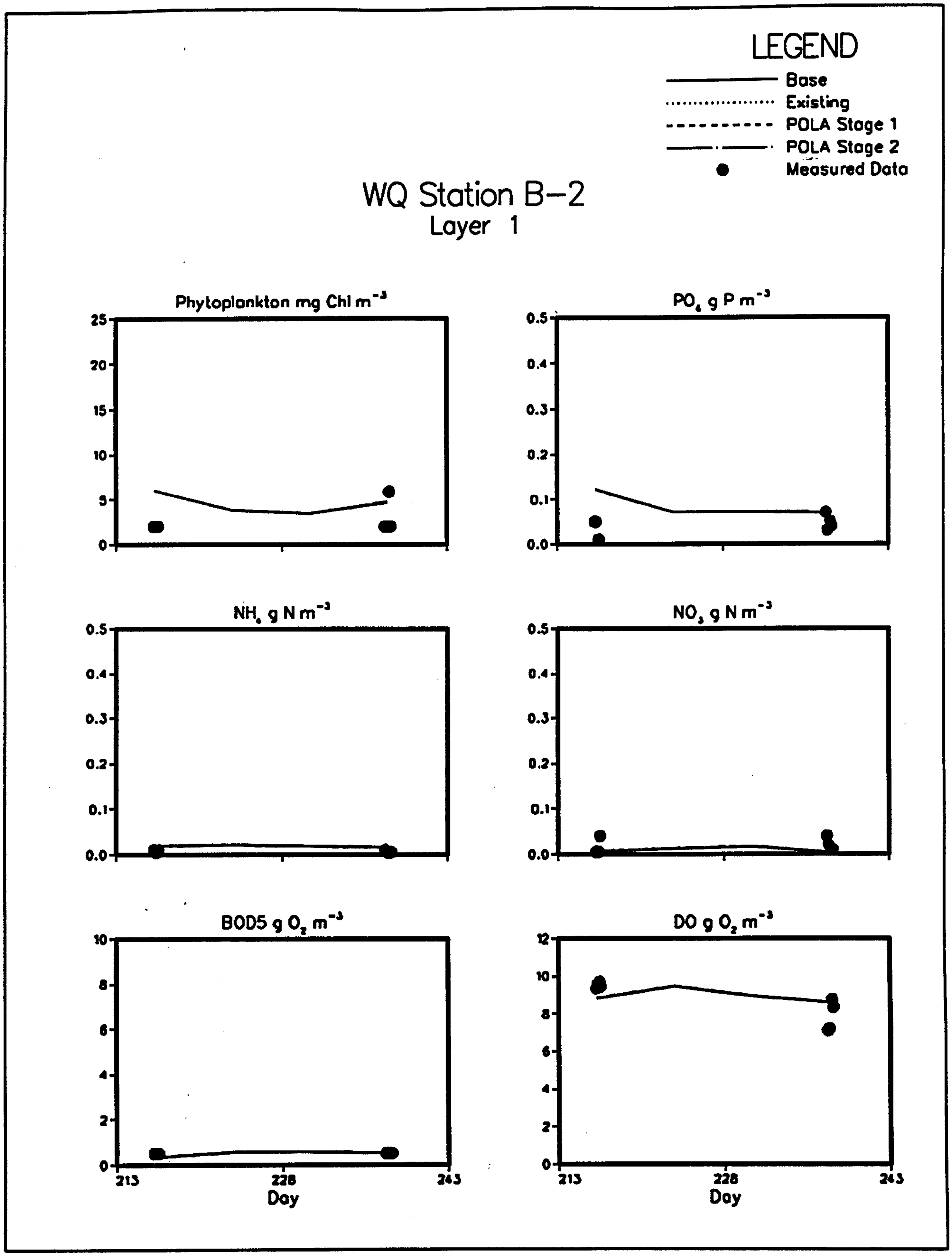

LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
Measured Data
WQ Station I–11
Layer 1
Phytoplankton mg Chl m⁻³
PO4 g P m⁻³
NH4 g N m⁻³
NO3 g N m⁻³
BOD5 g O2 m⁻³
DO g O2 m⁻³
Day
Day

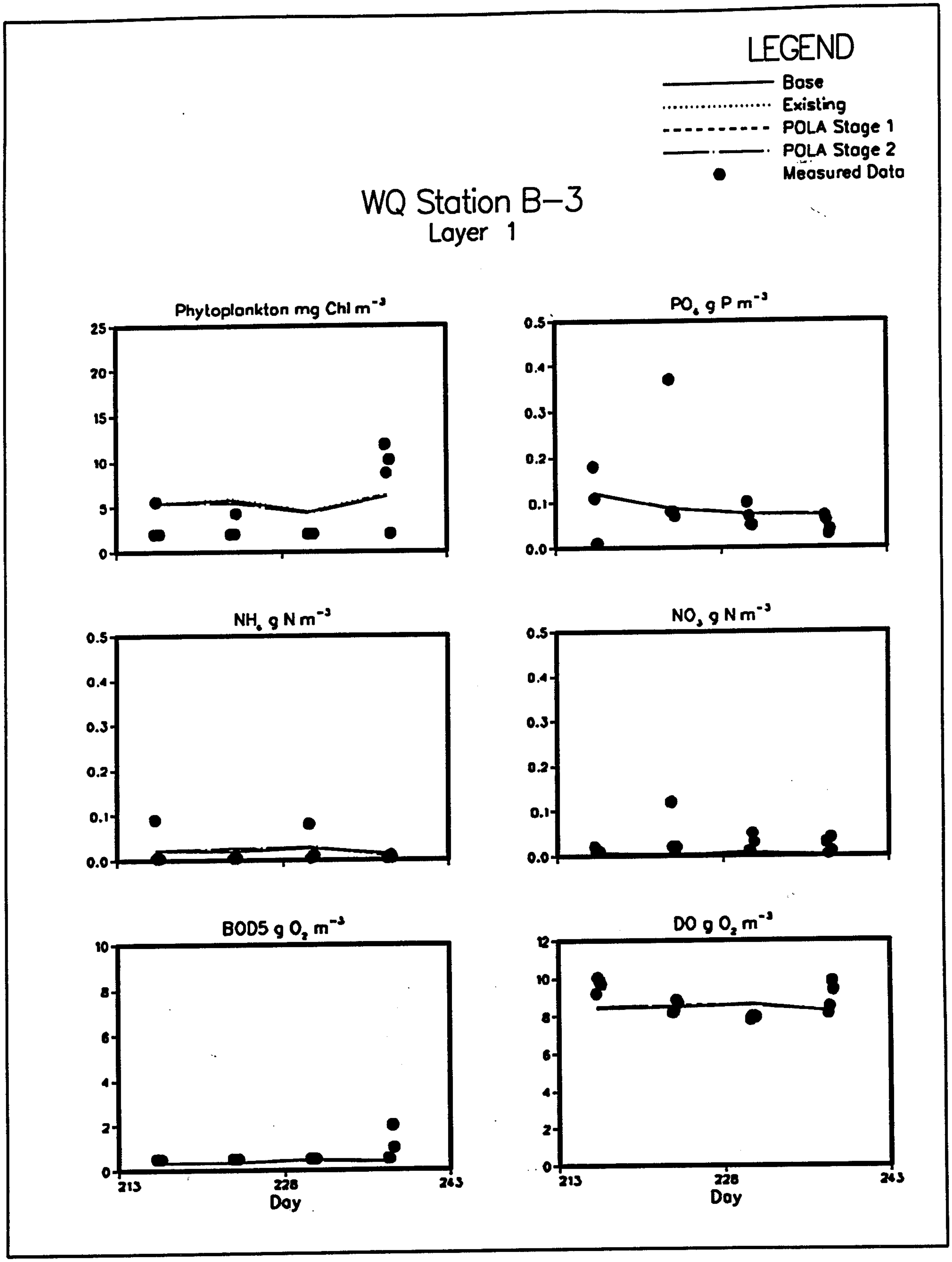
Plate B11



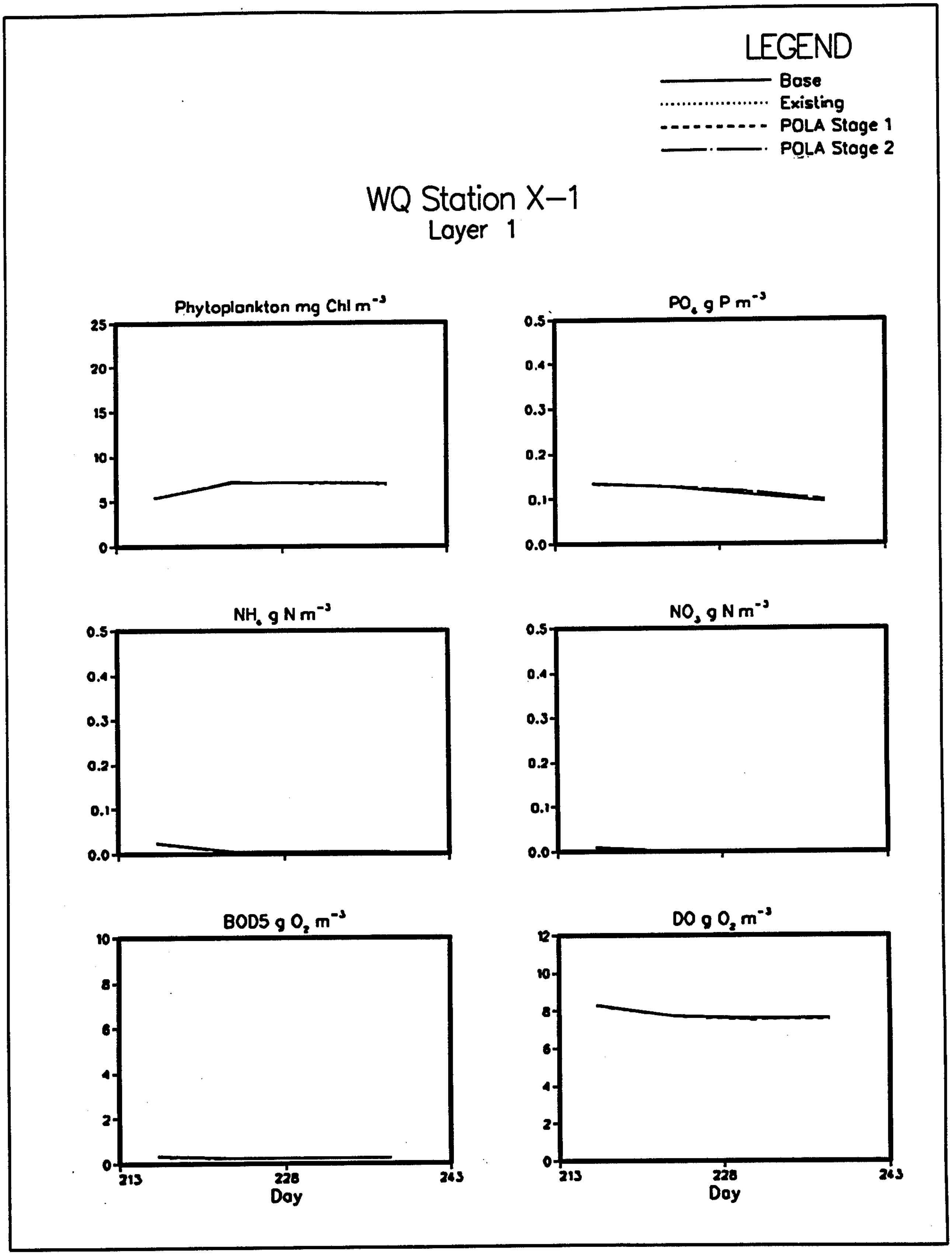
LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
Measured Data
WQ Station B-1
Layer 1
Phytoplankton mg Chl m^-3
PO4 g P m^-3
NH4 g N m^-3
NO3 g N m^-3
BOD5 g O2 m^-3
DO g O2 m^-3
213
228
243
Day

Plate B12


LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
Measured Data
WQ Station B-2
Layer 1
Phytoplankton mg Chl m-3
PO4 g P m-3
NH4 g N m-3
NO3 g N m-3
BOD5 g O2 m-3
DO g O2 m-3
Day
Day



LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
Measured Data
WQ Station B-3
Layer 1
Phytoplankton mg Chl m⁻³
PO4 g P m⁻³
NH4 g N m⁻³
NO3 g N m⁻³
BOD5 g O2 m⁻³
DO g O2 m⁻³
213
228
243
Day


LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
WQ Station X-1
Layer 1
Phytoplankton mg Chl m-3
PO4 g P m-3
NH4 g N m-3
NO3 g N m-3
BOD5 g O2 m-3
DO g O2 m-3
213
228
243
Day

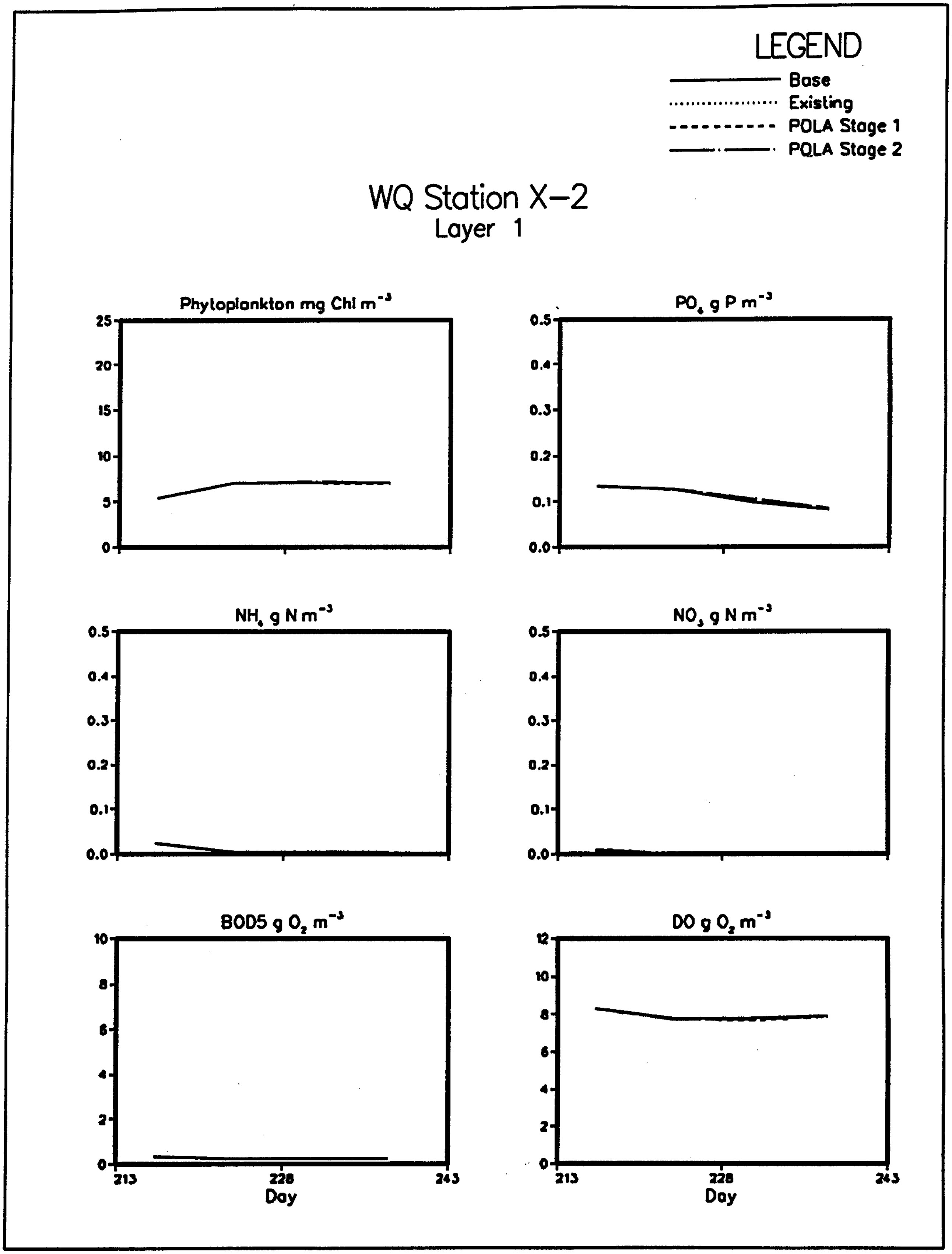
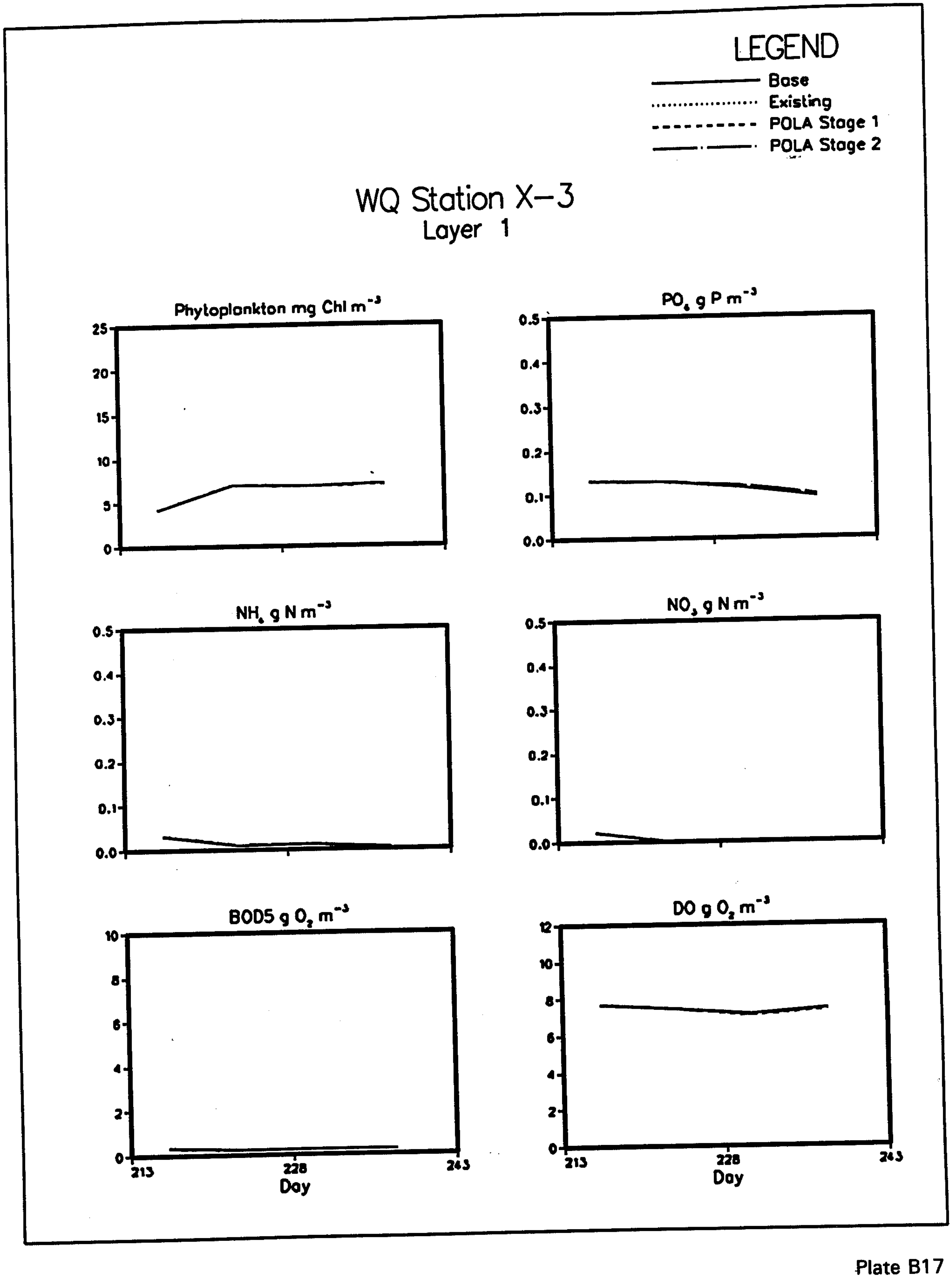
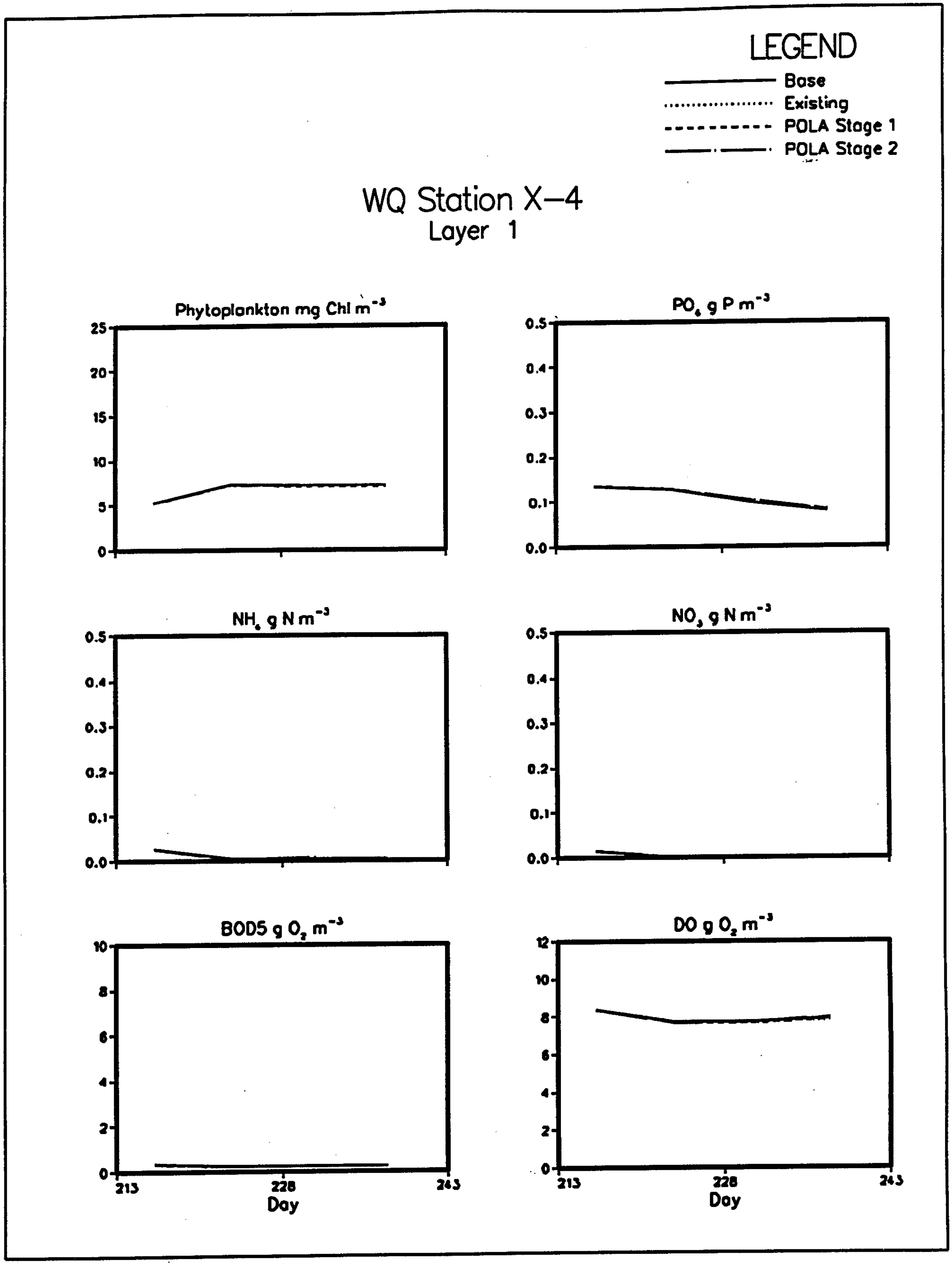

LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
WQ Station X-2
Layer 1
Phytoplankton mg Chl m-3
PO4 g P m-3
NH4 g N m-3
NO3 g N m-3
BOD5 g O2 m-3
DO g O2 m-3
213
228
243
Day

Plate B16



LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
WQ Station X-3
Layer 1
Phytoplankton mg Chl m-3
PO4 g P m-3
NH4 g N m-3
NO3 g N m-3
BOD5 g O2 m-3
DO g O2 m-3
213
228
243
Day

Plate B17



LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
WQ Station X–4
Layer 1
Phytoplankton mg Chl m^-3
PO4 g P m^-3
NH4 g N m^-3
NO3 g N m^-3
BOD5 g O2 m^-3
DO g O2 m^-3
213
228
243
Day

Plate B18

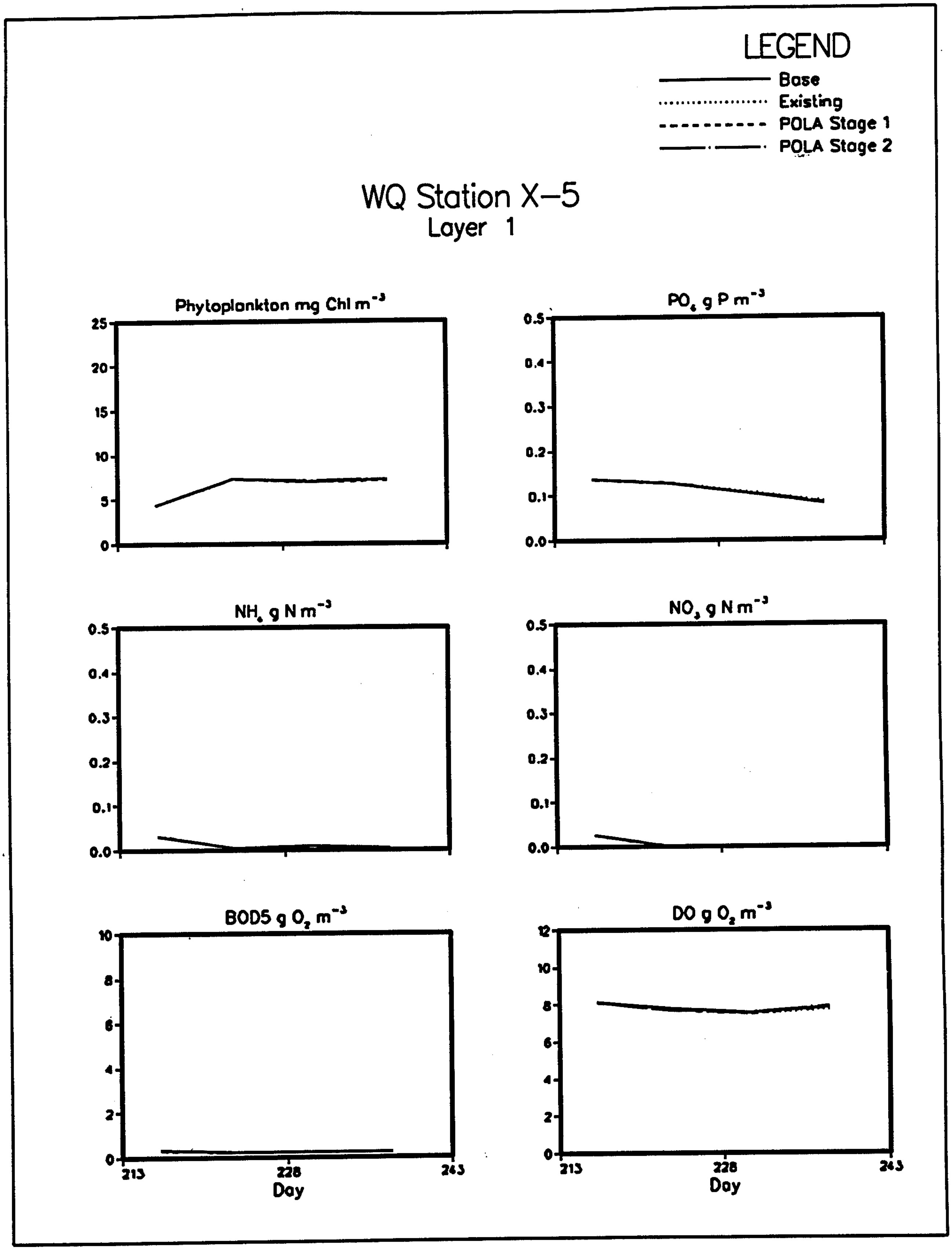
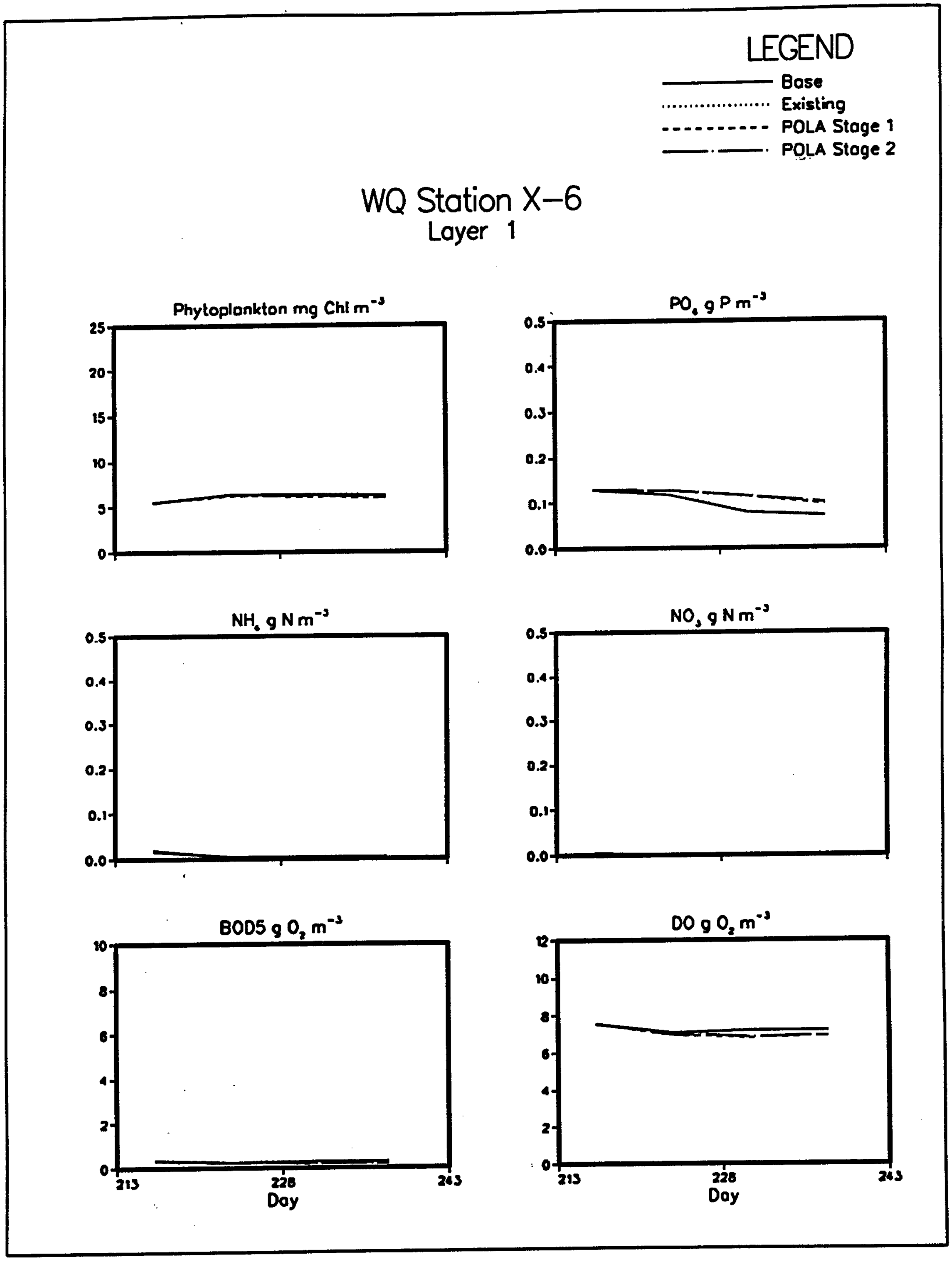
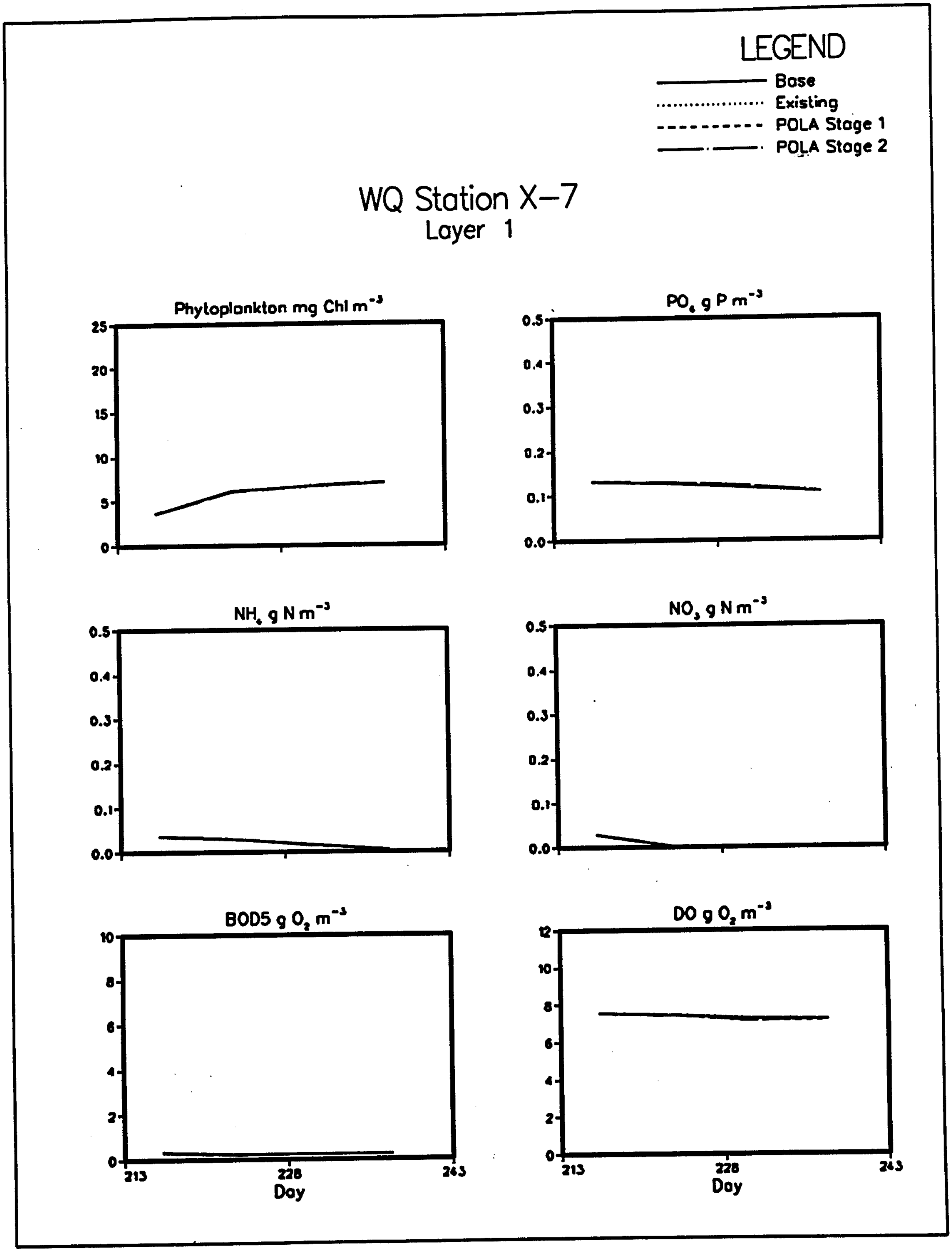

LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
WQ Station X–5
Layer 1
Phytoplankton mg Chl m-3
PO4 g P m-3
NH4 g N m-3
NO3 g N m-3
BOD5 g O2 m-3
DO g O2 m-3
213
228
243
Day

Plate B19



LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
WQ Station X–6
Layer 1
Phytoplankton mg Chl m⁻³
PO₄ g P m⁻³
NH₄ g N m⁻³
NO₃ g N m⁻³
BOD5 g O₂ m⁻³
DO g O₂ m⁻³
213
228
243
Day

Plate B20


LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
WQ Station X-7
Layer 1
Phytoplankton mg Chl m^{-3}
PO_4 g P m^{-3}
NH_4 g N m^{-3}
NO_3 g N m^{-3}
BOD5 g O_2 m^{-3}
DO g O_2 m^{-3}
213
228
243
Day

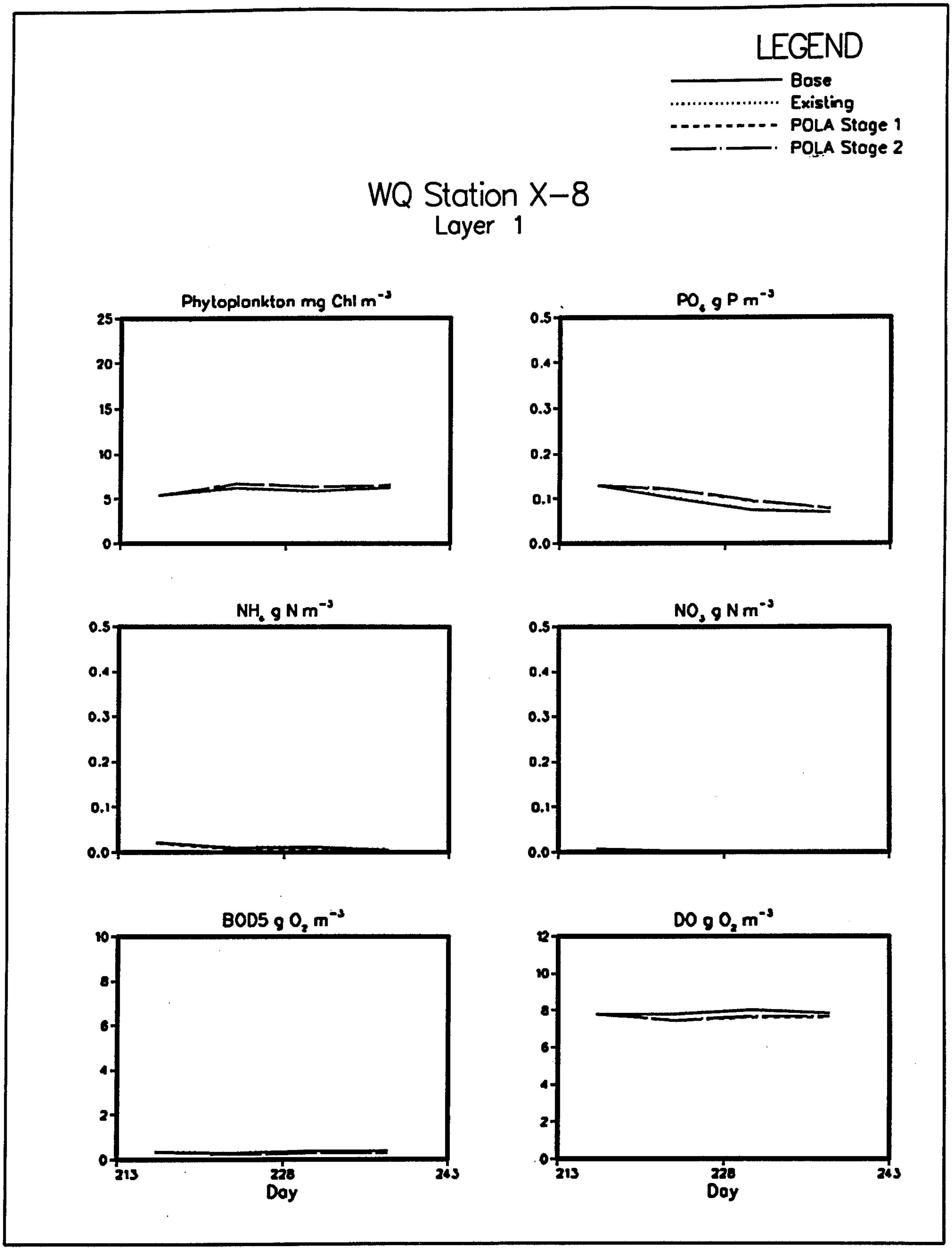
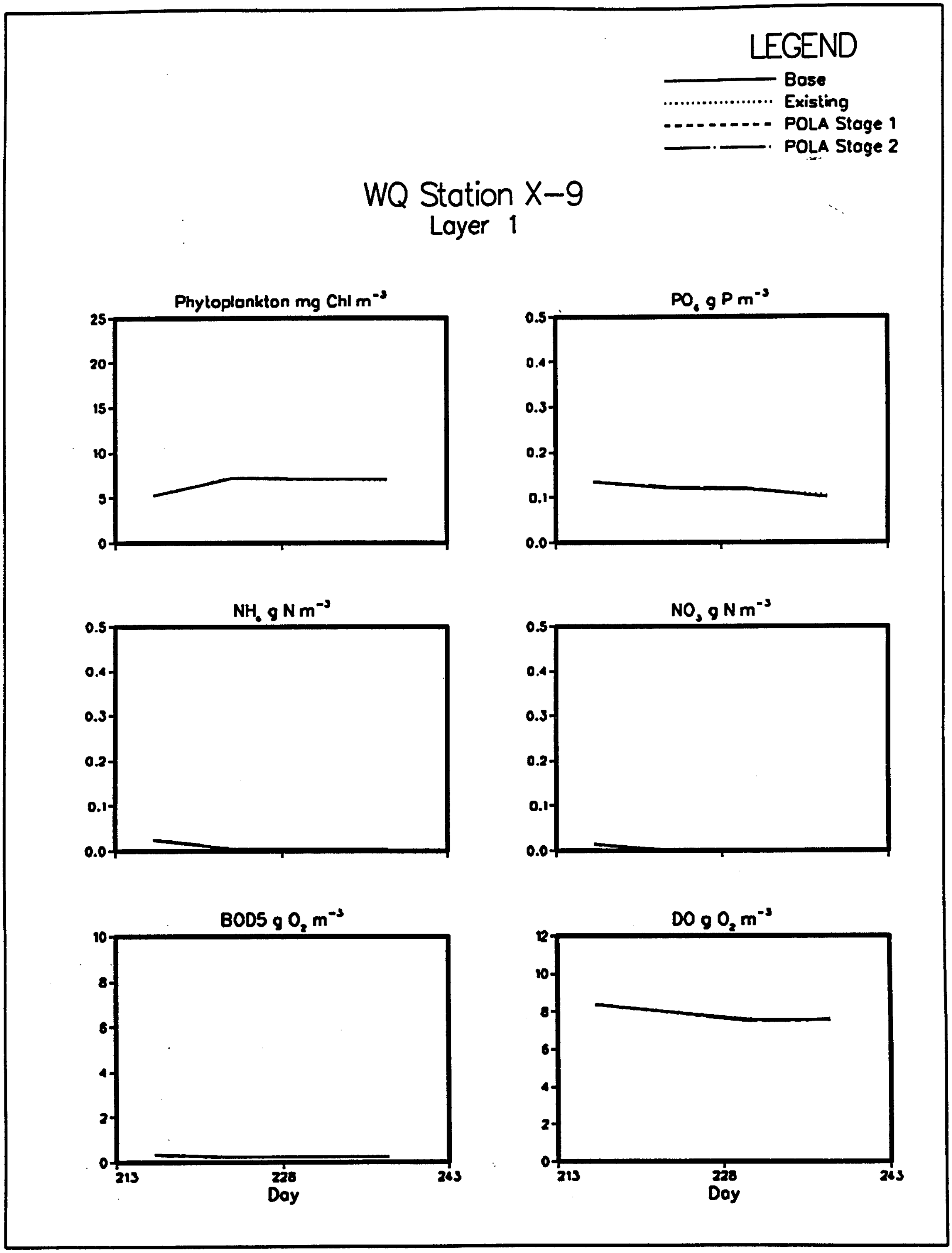

LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
WQ Station X-8
Layer 1
Phytoplankton mg Chl m^-3
PO4 g P m^-3
NH4 g N m^-3
NO3 g N m^-3
BOD5 g O2 m^-3
DO g O2 m^-3
213
228
243
Day

Plate B22



LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
WQ Station X-9
Layer 1
Phytoplankton mg Chl m-3
PO4 g P m-3
NH4 g N m-3
NO3 g N m-3
BOD5 g O2 m-3
DO g O2 m-3
213
228
243
Day

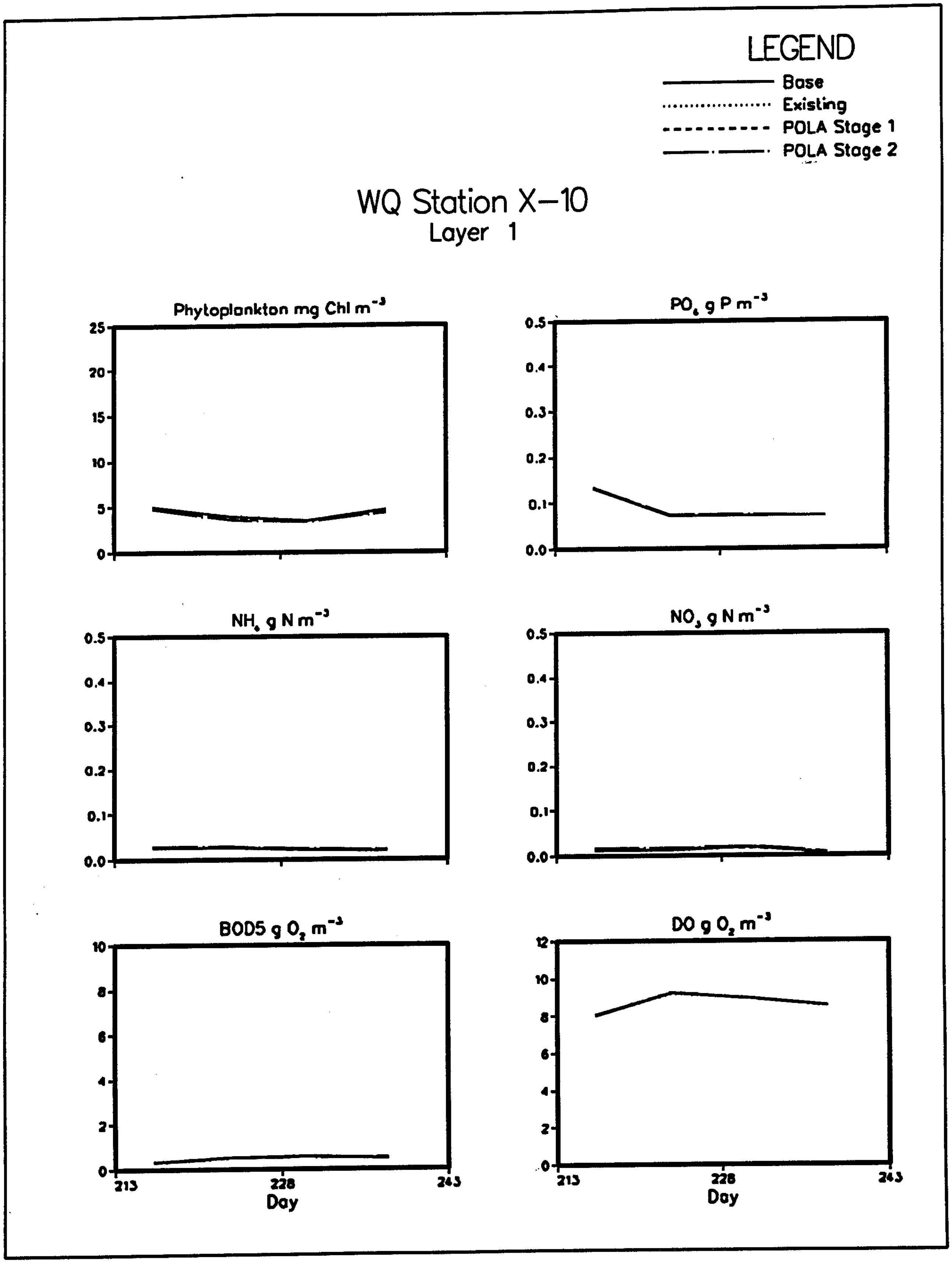
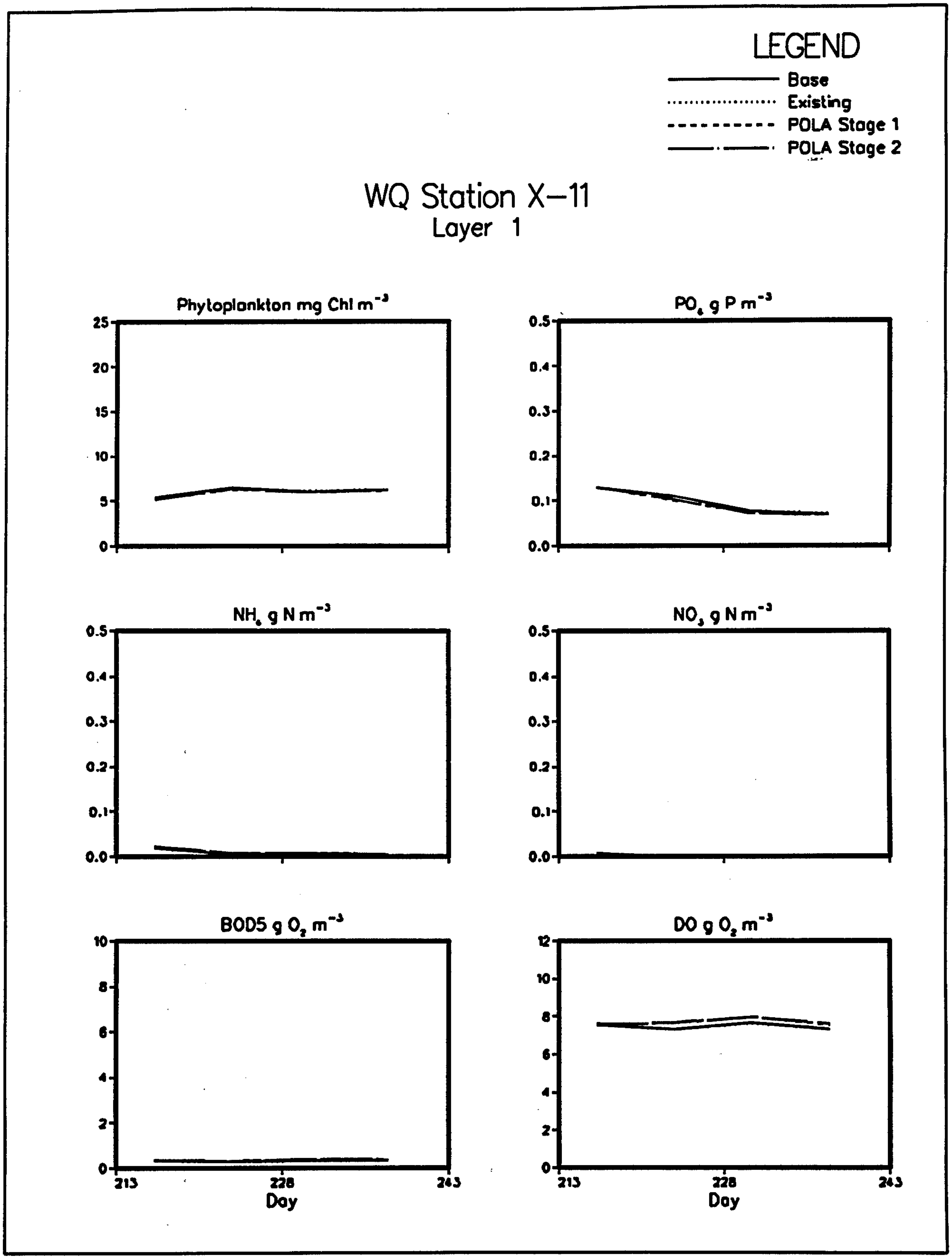

LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
WQ Station X-10
Layer 1
Phytoplankton mg Chl m-3
PO4 g P m-3
NH4 g N m-3
NO3 g N m-3
BOD5 g O2 m-3
DO g O2 m-3
213
228
243
Day

Plate B24



LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
WQ Station X-11
Layer 1
Phytoplankton mg Chl m-3
PO4 g P m-3
NH4 g N m-3
NO3 g N m-3
BOD5 g O2 m-3
DO g O2 m-3
213
228
243
Day

Plate B25

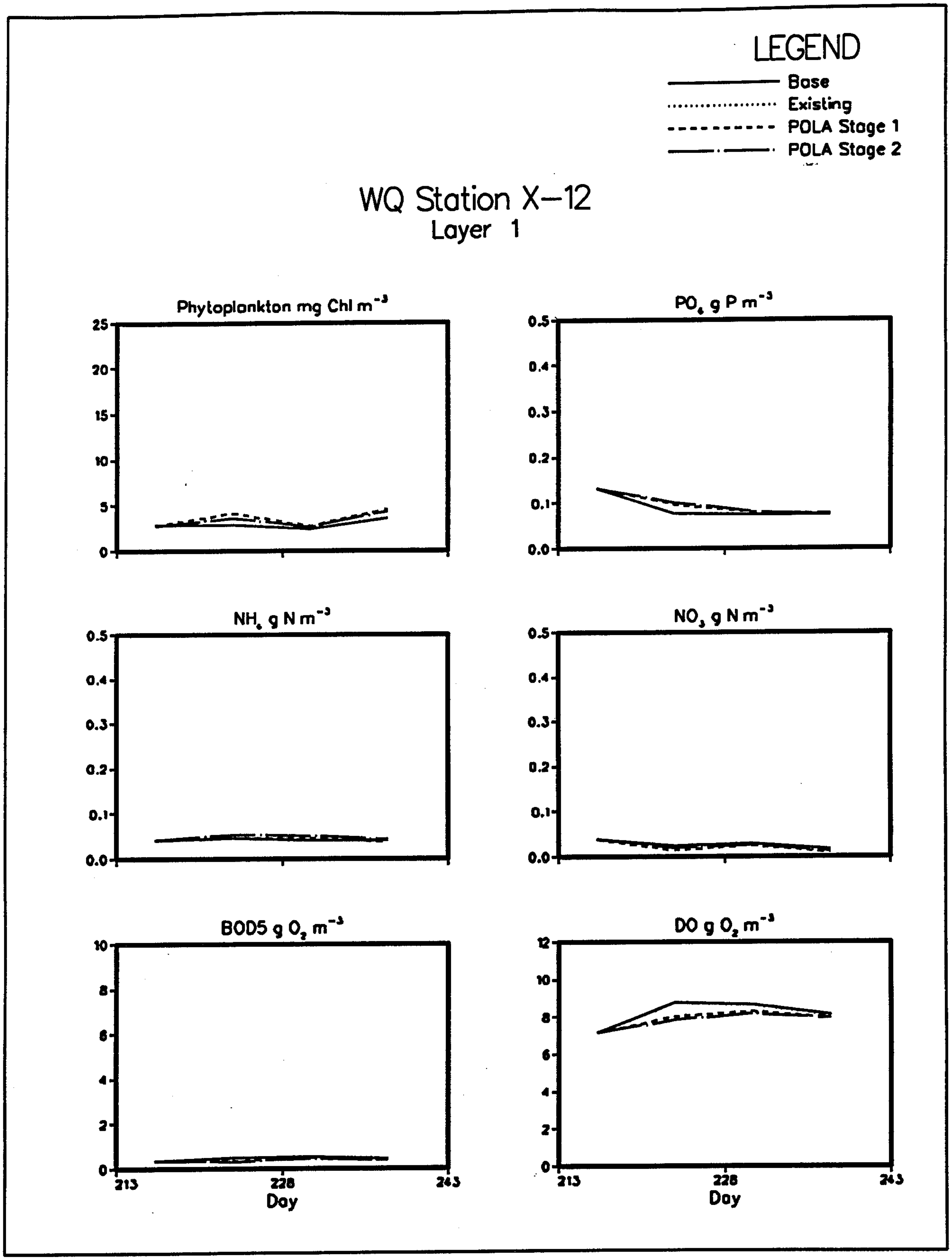
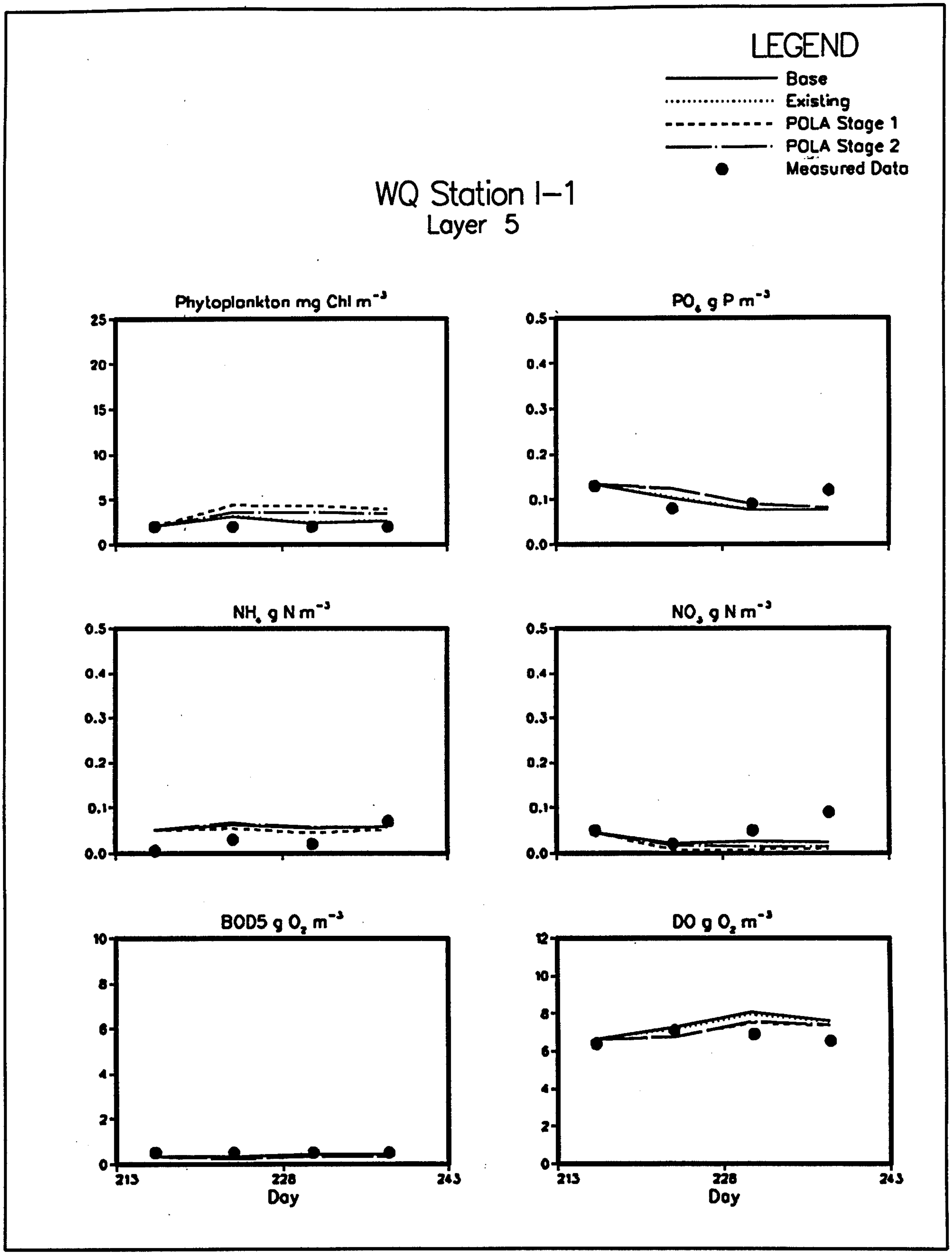
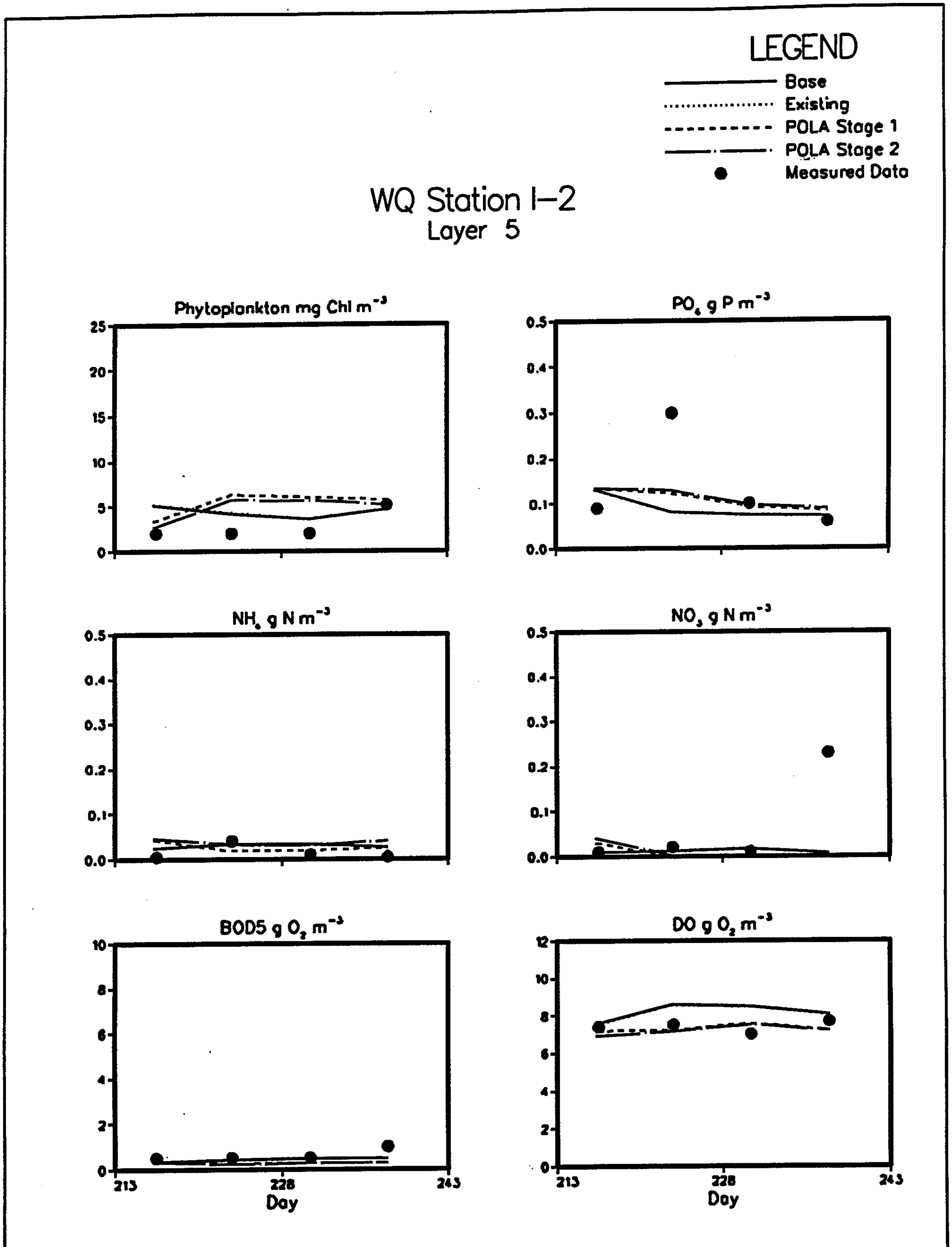
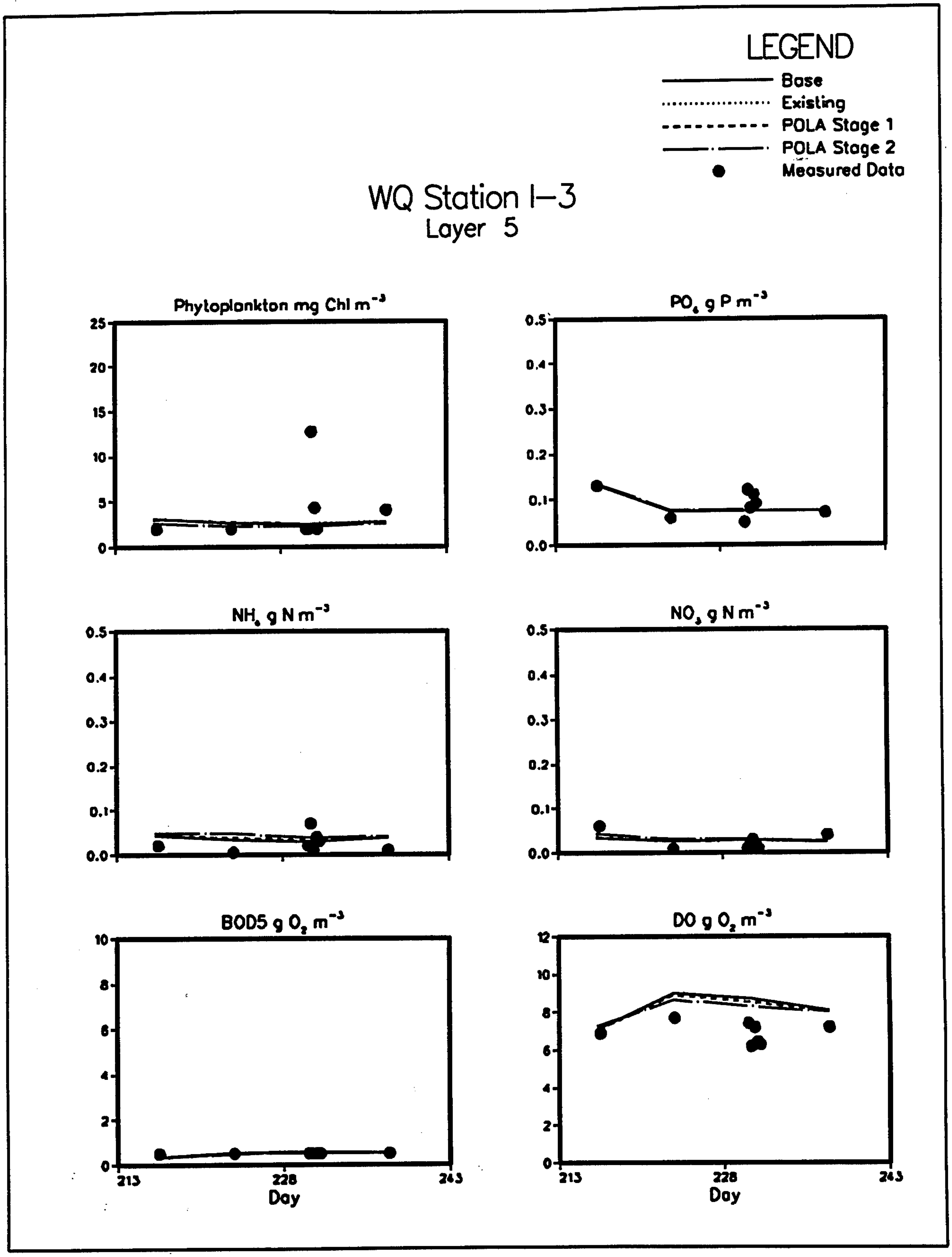

LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
WQ Station X-12
Layer 1
Phytoplankton mg Chl m^{-3}
PO_4 g P m^{-3}
NH_4 g N m^{-3}
NO_3 g N m^{-3}
BOD5 g O_2 m^{-3}
DO g O_2 m^{-3}
213
228
243
Day

Plate B26

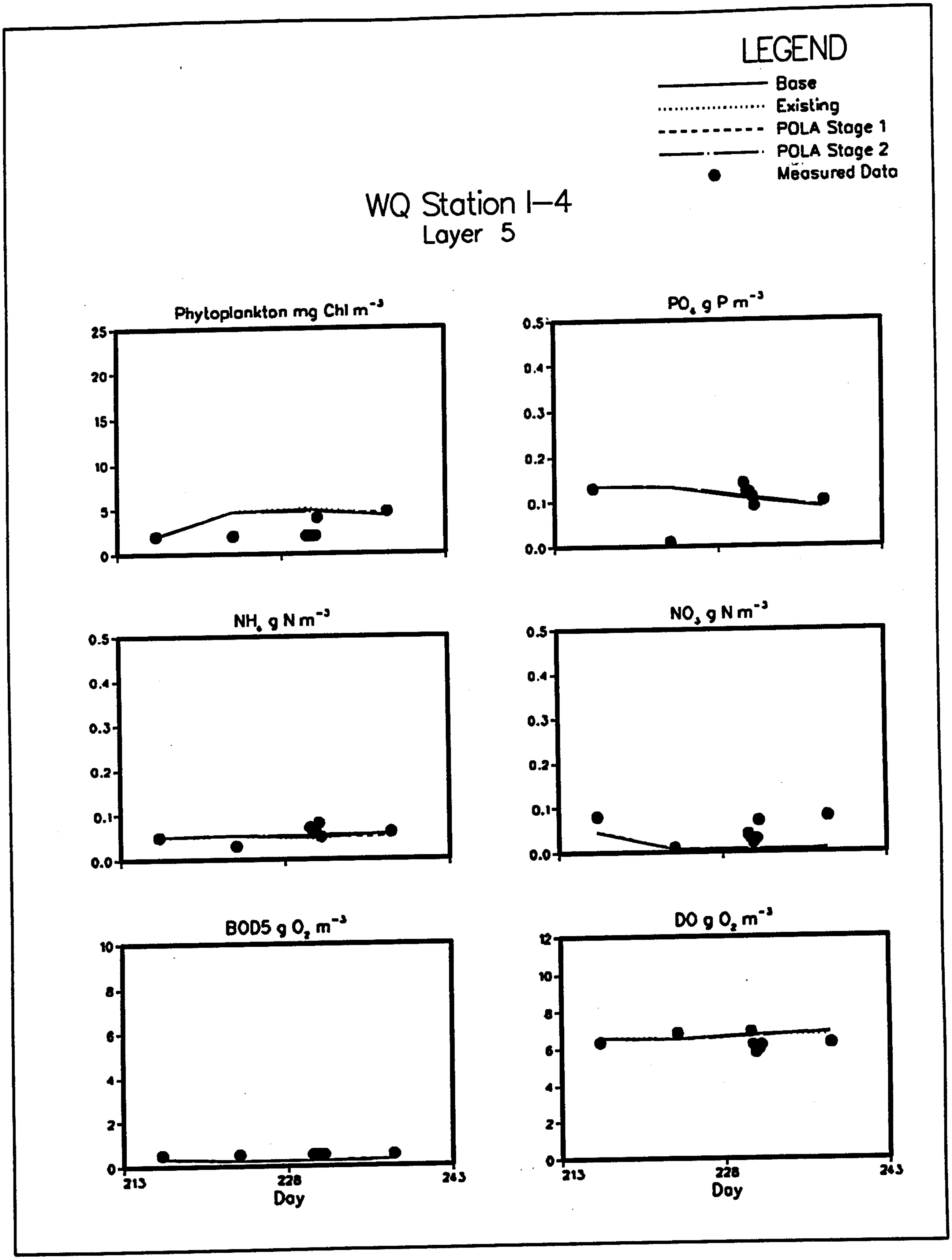

LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
Measured Data
WQ Station I-1
Layer 5
Phytoplankton mg Chl m^-3
PO4 g P m^-3
NH4 g N m^-3
NO3 g N m^-3
BOD5 g O2 m^-3
DO g O2 m^-3
213
228
243
Day

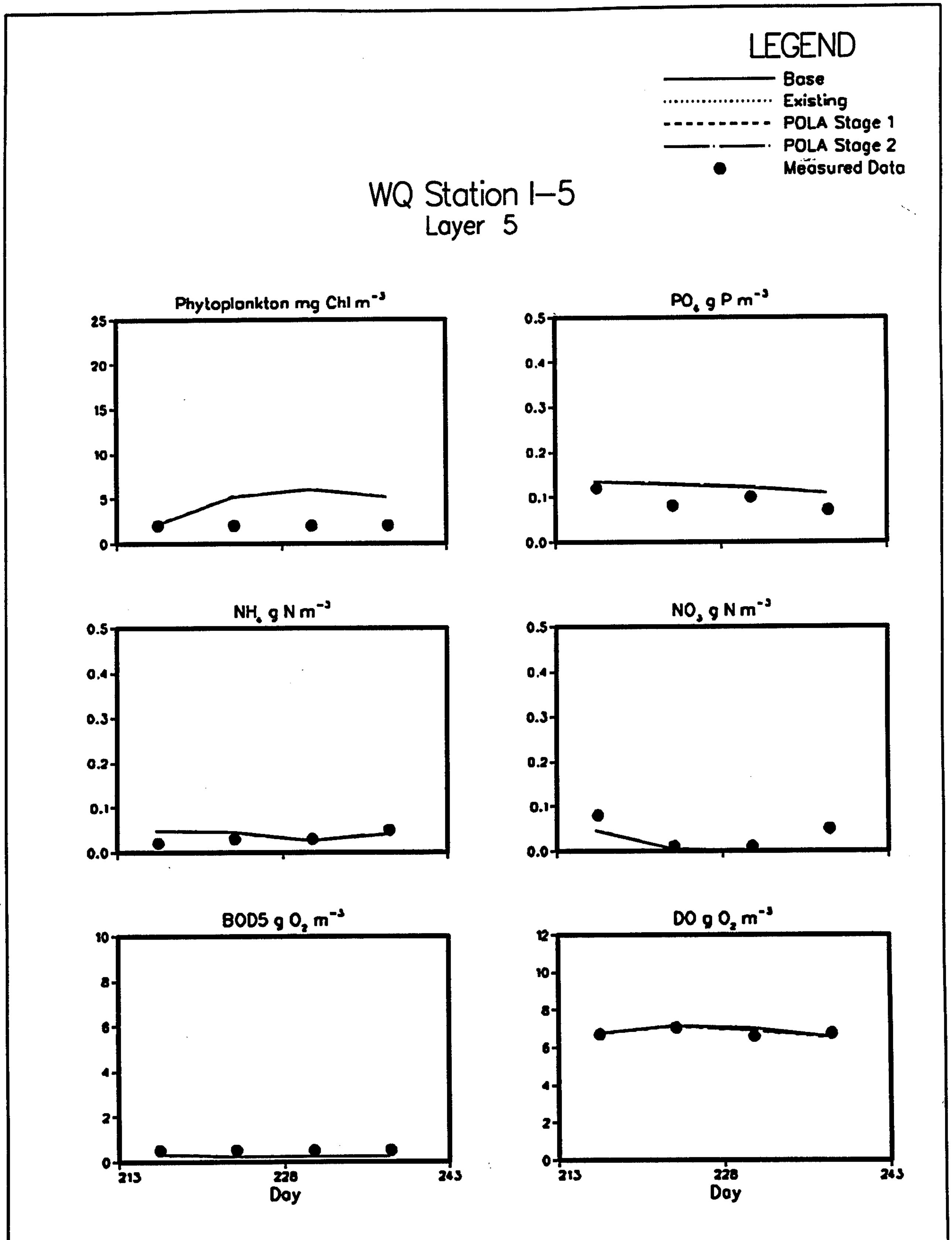


LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
Measured Data
WQ Station I-2
Layer 5
Phytoplankton mg Chl m-3
PO4 g P m-3
NH4 g N m-3
NO3 g N m-3
BOD5 g O2 m-3
DO g O2 m-3
213
228
243
Day

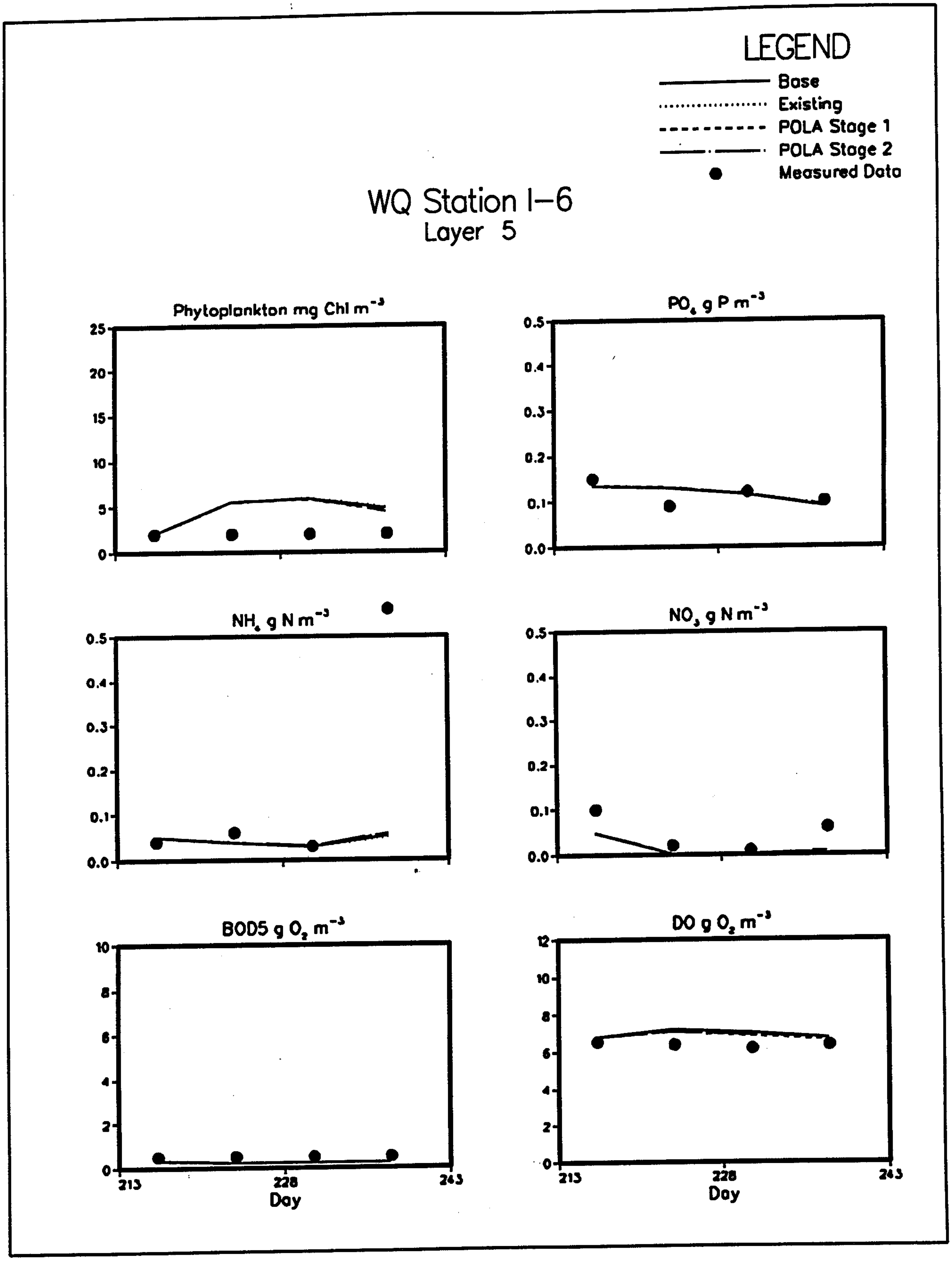


LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
Measured Data
WQ Station I–3
Layer 5
Phytoplankton mg Chl m⁻³
PO₄ g P m⁻³
NH₄ g N m⁻³
NO₃ g N m⁻³
BOD5 g O₂ m⁻³
DO g O₂ m⁻³
213
228
243
Day


LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
Measured Data
WQ Station I-4
Layer 5
Phytoplankton mg Chl m-3
PO4 g P m-3
NH4 g N m-3
NO3 g N m-3
BOD5 g O2 m-3
DO g O2 m-3
Day
Day
213
228
243

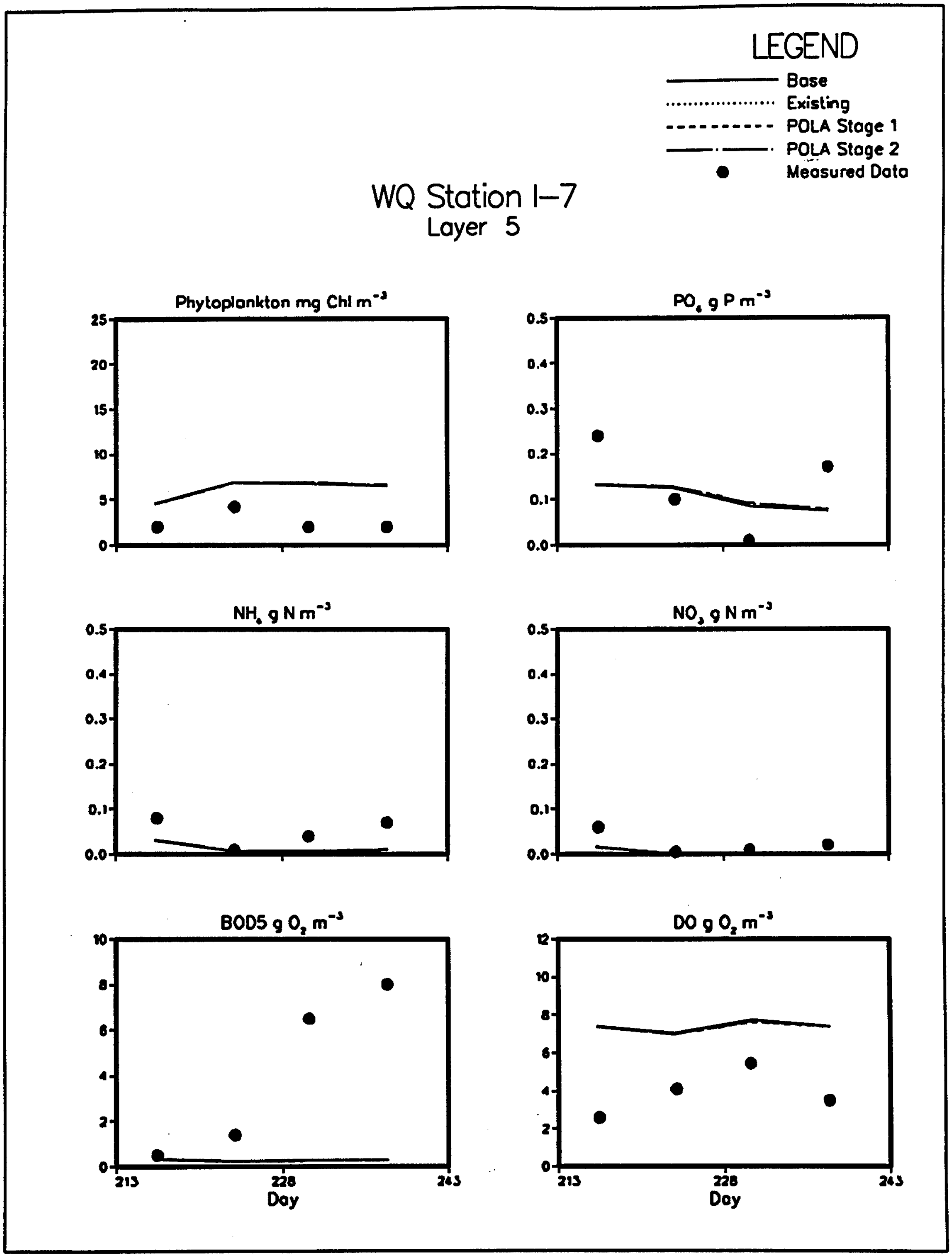


LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
Measured Data
WQ Station I–5
Layer 5
Phytoplankton mg Chl m^-3
PO4 g P m^-3
NH4 g N m^-3
NO3 g N m^-3
BOD5 g O2 m^-3
DO g O2 m^-3
213
228
243
Day



LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
Measured Data
WQ Station I-6
Layer 5
Phytoplankton mg Chl m-3
PO4 g P m-3
NH4 g N m-3
NO3 g N m-3
BOD5 g O2 m-3
DO g O2 m-3
Day
213
228
243

Plate B32


LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
Measured Data
WQ Station I–7
Layer 5
Phytoplankton mg Chl m⁻³
PO4 g P m⁻³
NH4 g N m⁻³
NO3 g N m⁻³
BOD5 g O2 m⁻³
DO g O2 m⁻³
213
228
243
Day

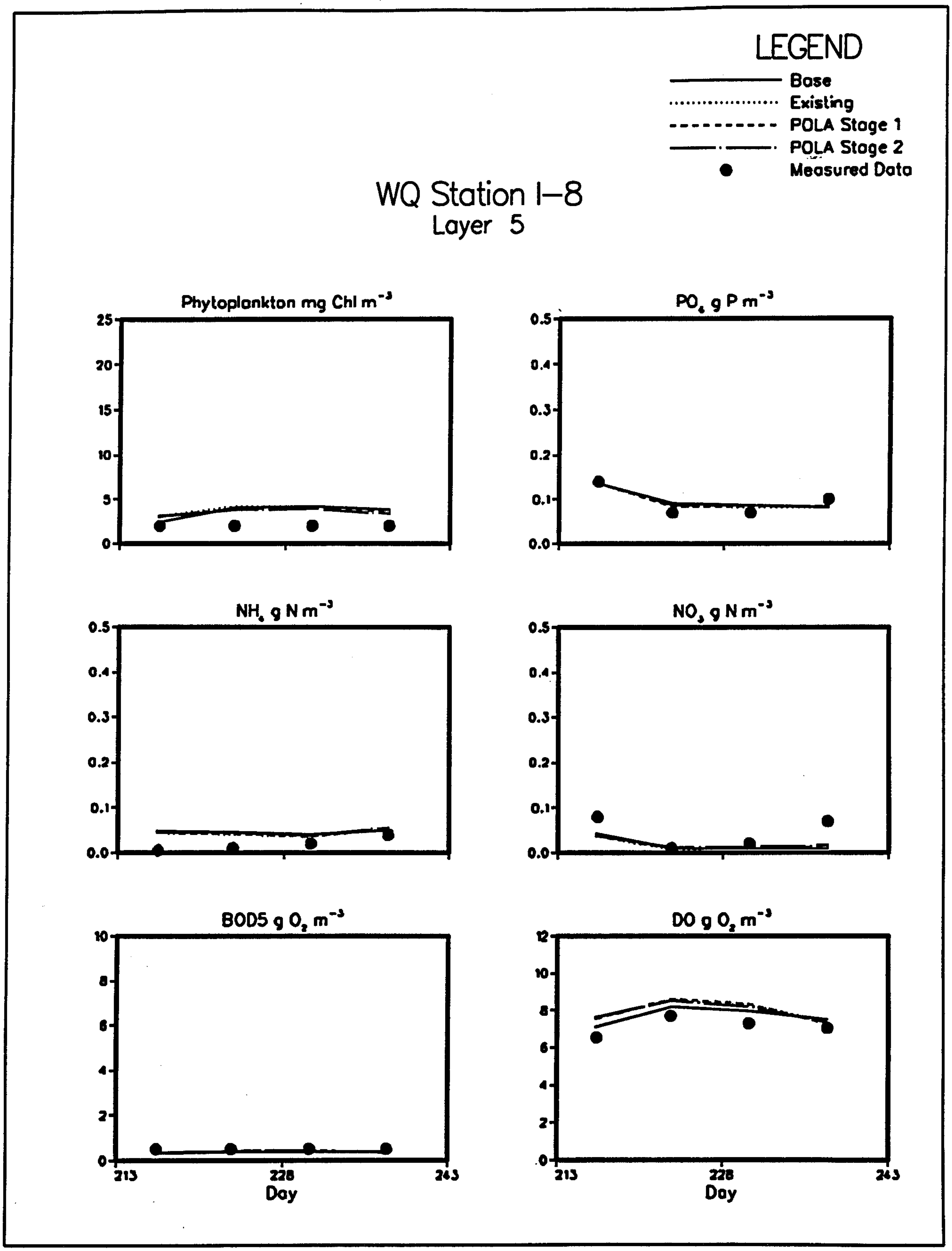
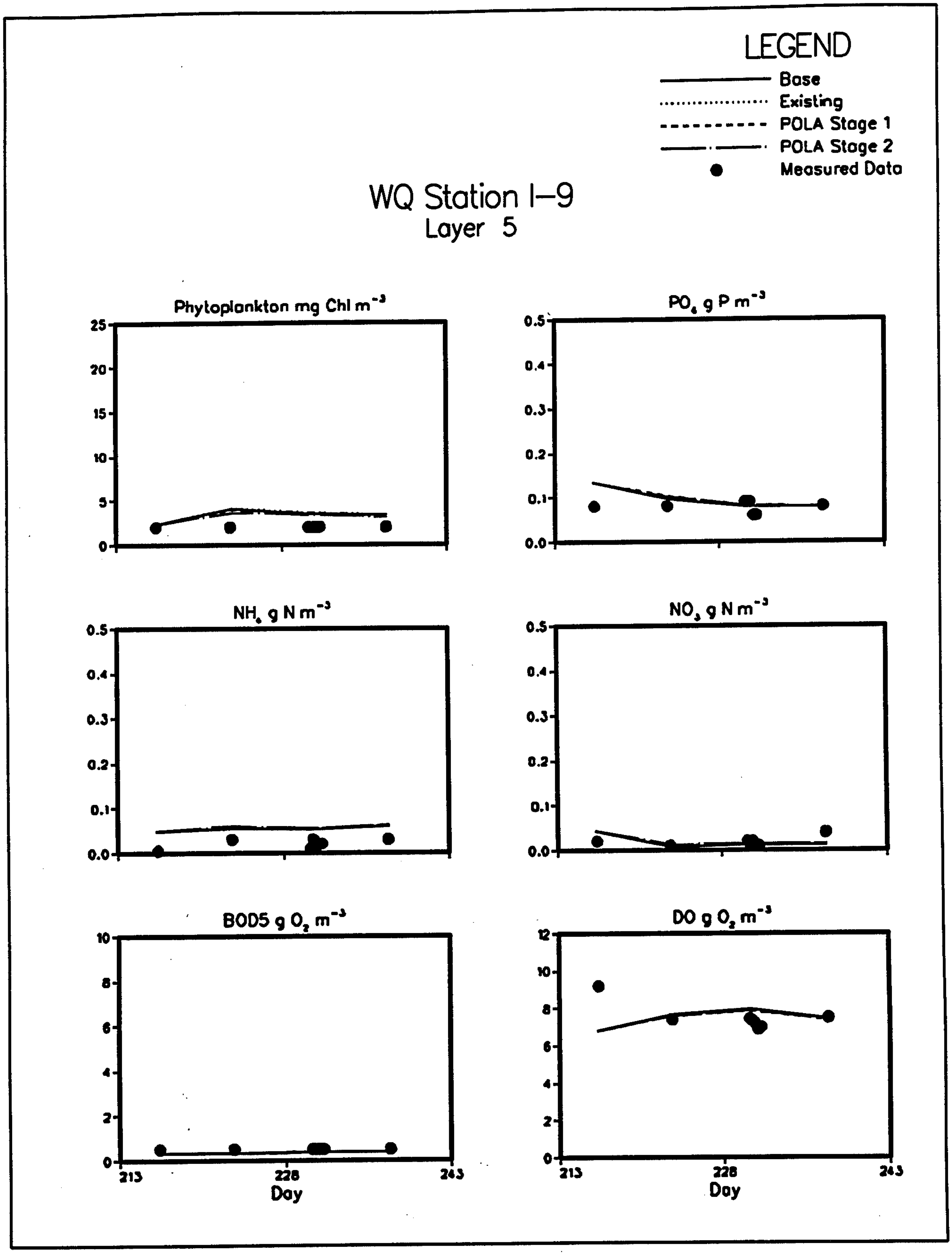
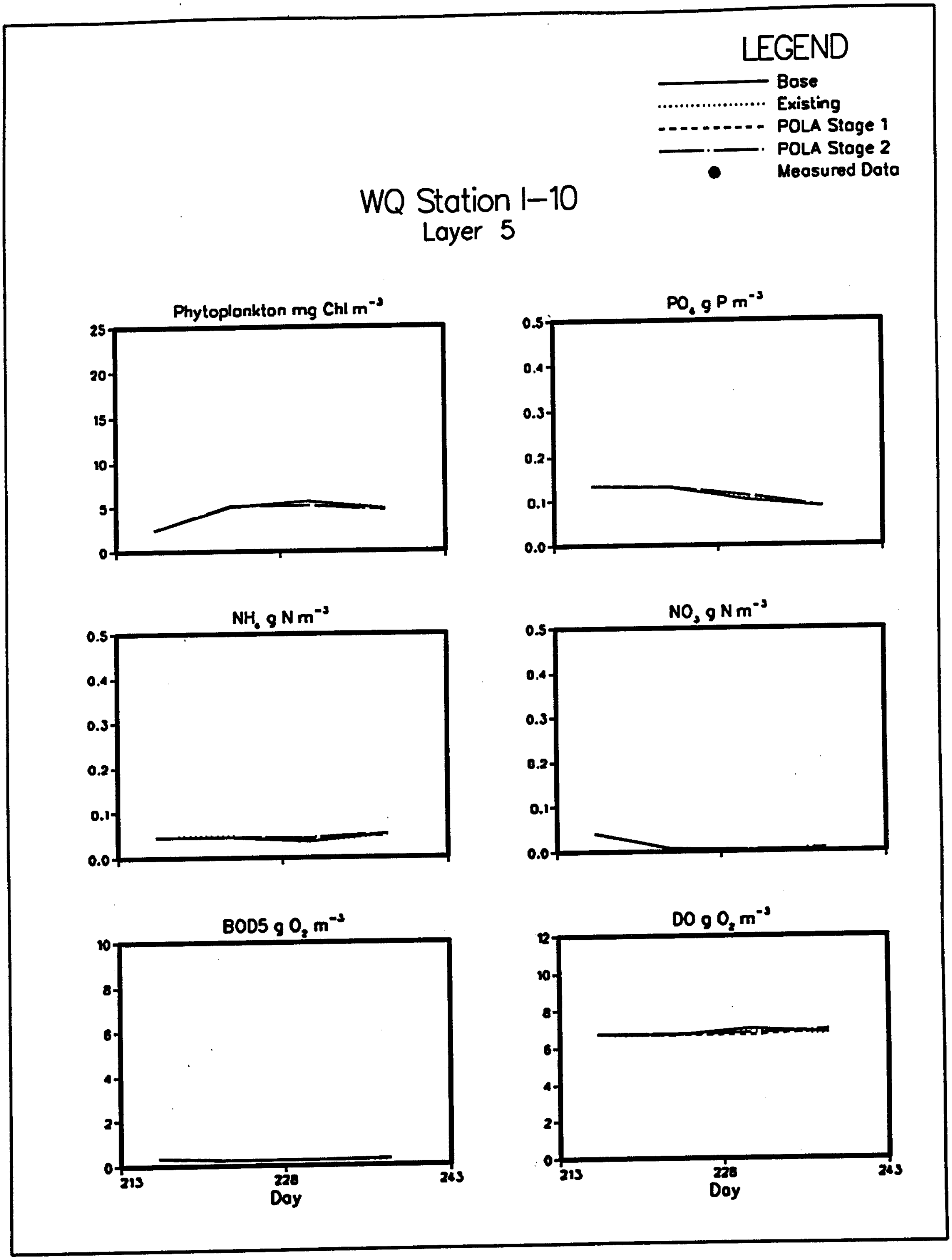

LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
Measured Data
WQ Station I-8
Layer 5
Phytoplankton mg Chl m^{-3}
PO_4 g P m^{-3}
NH_4 g N m^{-3}
NO_3 g N m^{-3}
BOD5 g O_2 m^{-3}
DO g O_2 m^{-3}
213
228
243
Day

Plate B34

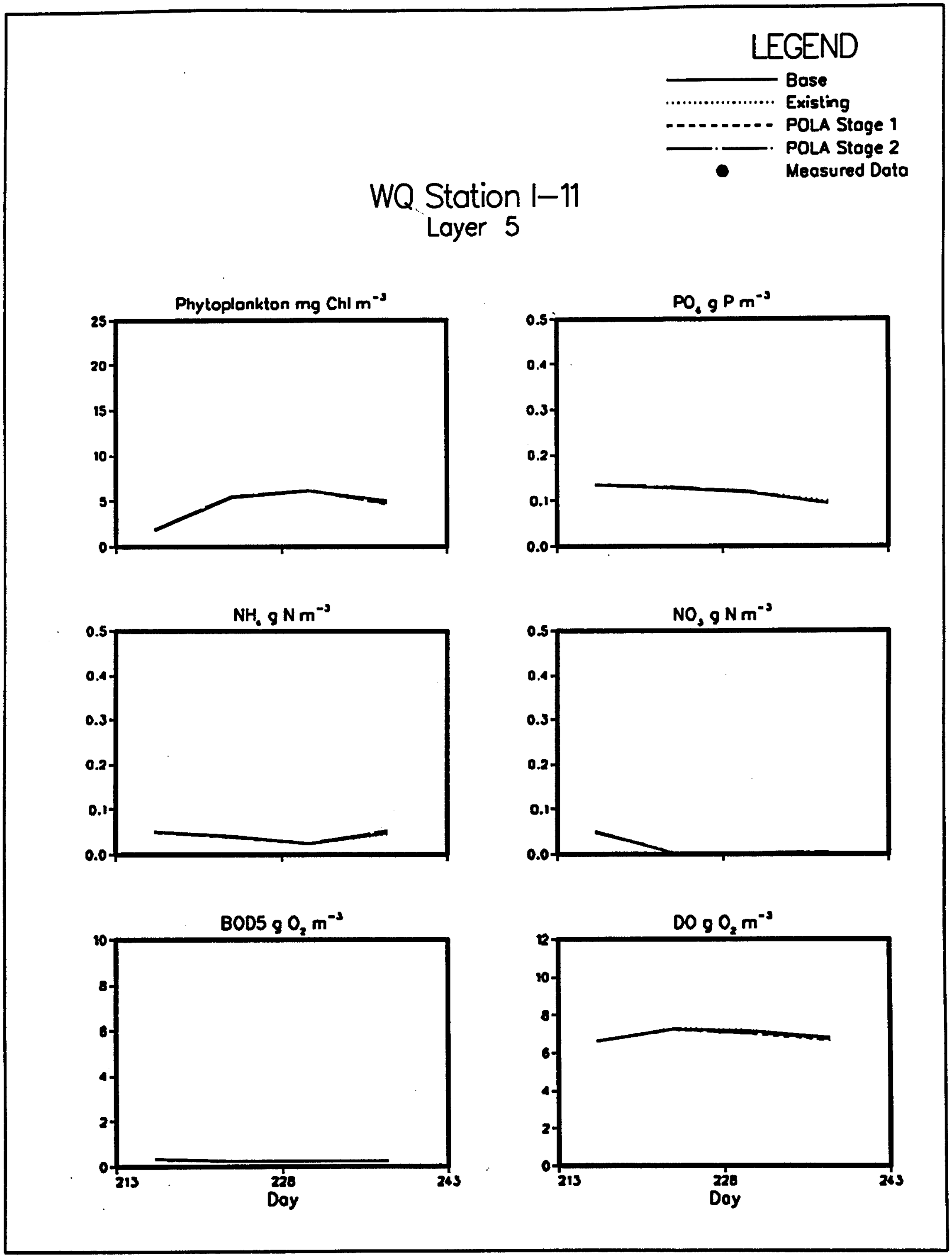


LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
Measured Data
WQ Station I–9
Layer 5
Phytoplankton mg Chl m⁻³
PO₄ g P m⁻³
NH₄ g N m⁻³
NO₃ g N m⁻³
BOD5 g O₂ m⁻³
DO g O₂ m⁻³
Day
213
228
243



LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
Measured Data
WQ Station I-10
Layer 5
Phytoplankton mg Chl m-3
PO4 g P m-3
NH4 g N m-3
NO3 g N m-3
BOD5 g O2 m-3
DO g O2 m-3
213
228
243
Day

Plate B36



LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
Measured Data
WQ Station I-11
Layer 5
Phytoplankton mg Chl m-3
PO4 g P m-3
NH4 g N m-3
NO3 g N m-3
BOD5 g O2 m-3
DO g O2 m-3
213
228
243
Day

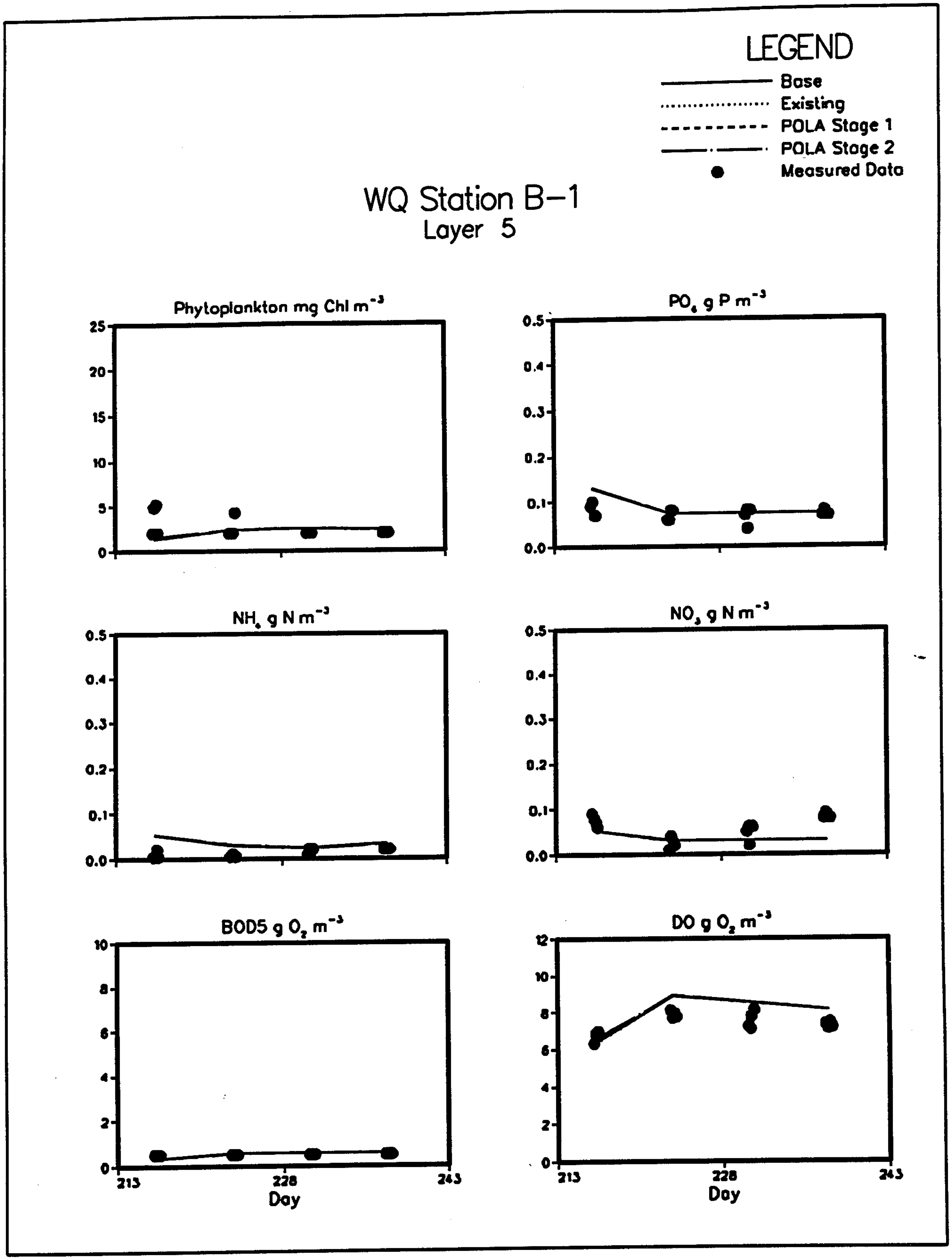
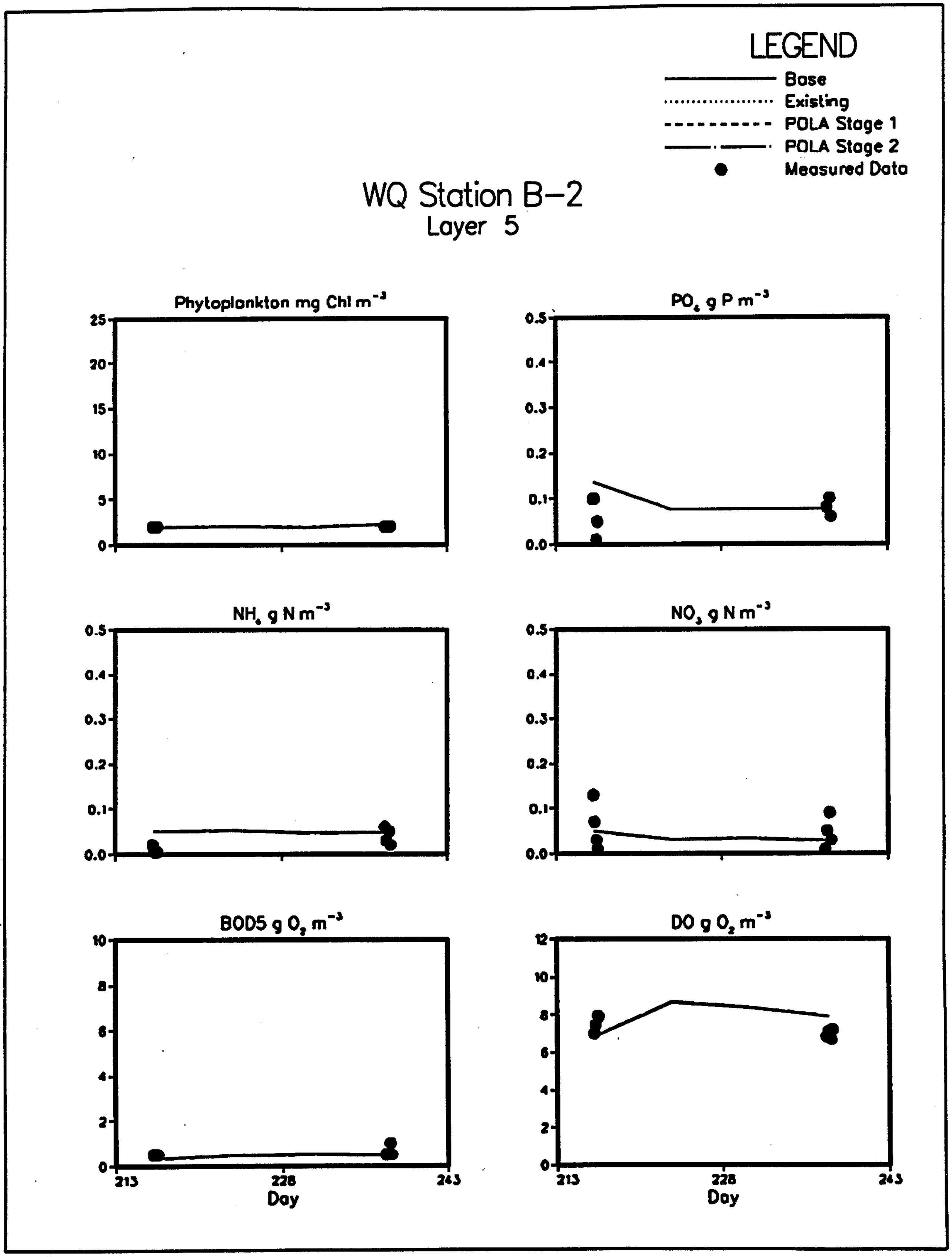
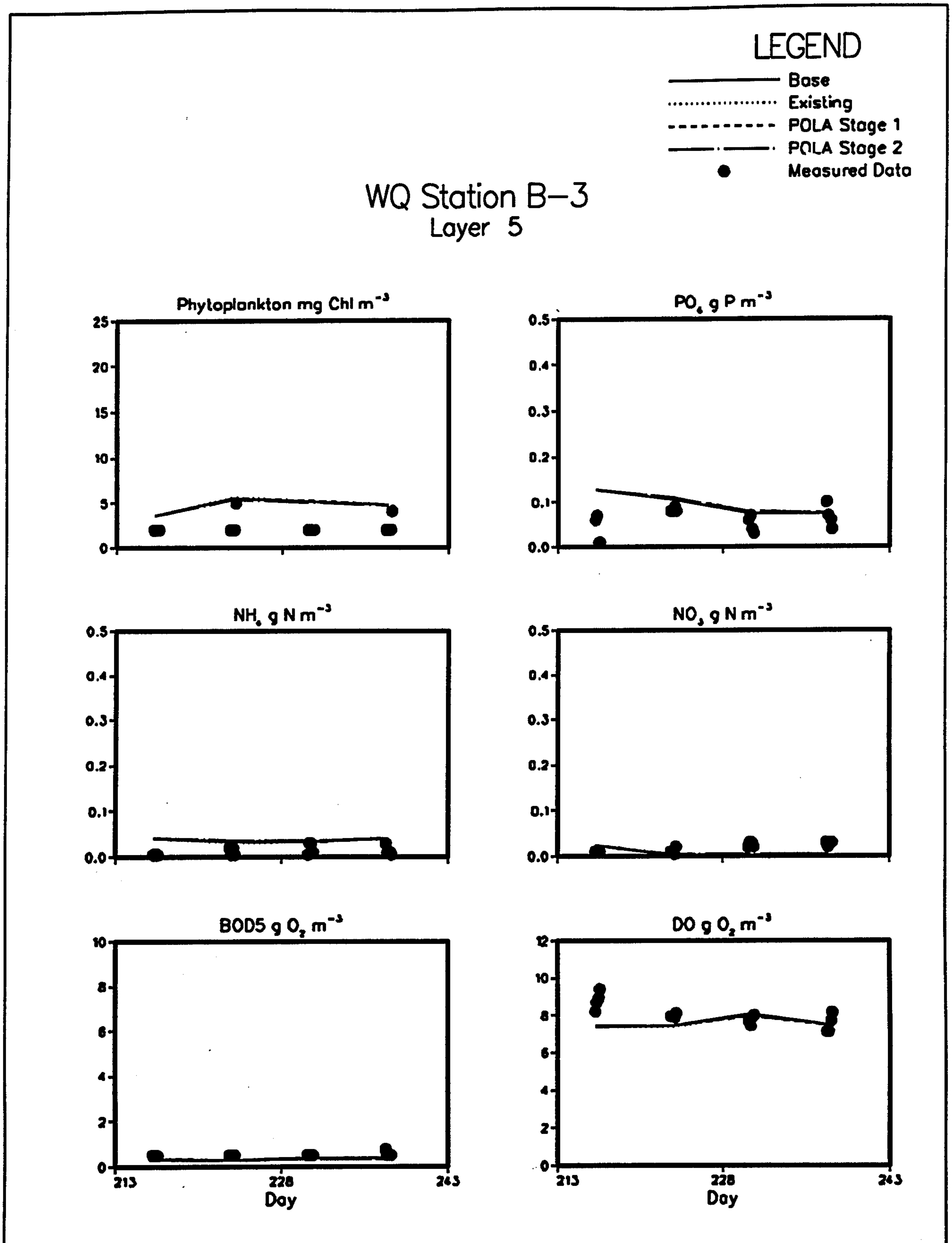
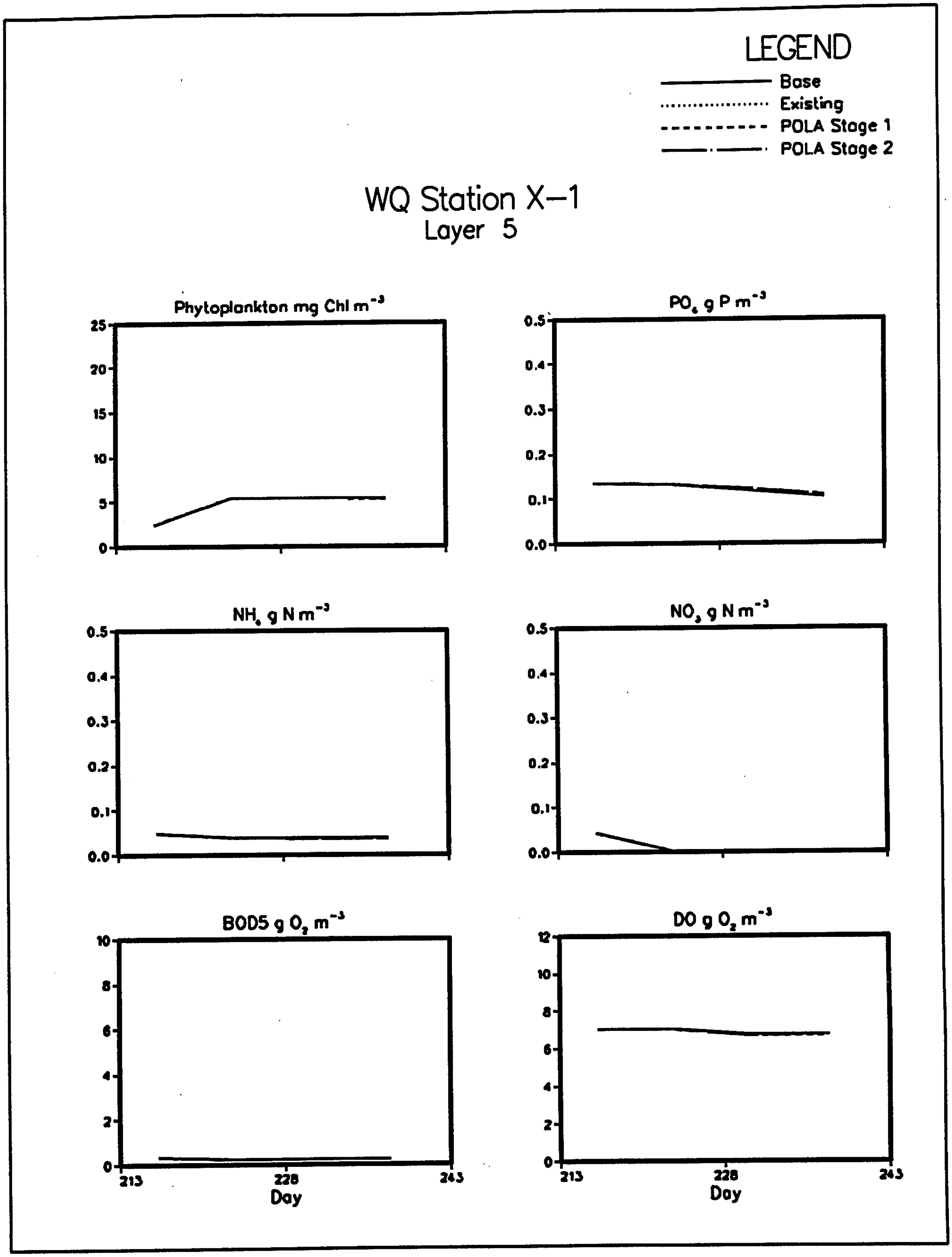

LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
Measured Data
WQ Station B-1
Layer 5
Phytoplankton mg Chl m-3
PO4 g P m-3
NH4 g N m-3
NO3 g N m-3
BOD5 g O2 m-3
DO g O2 m-3
Day
Day

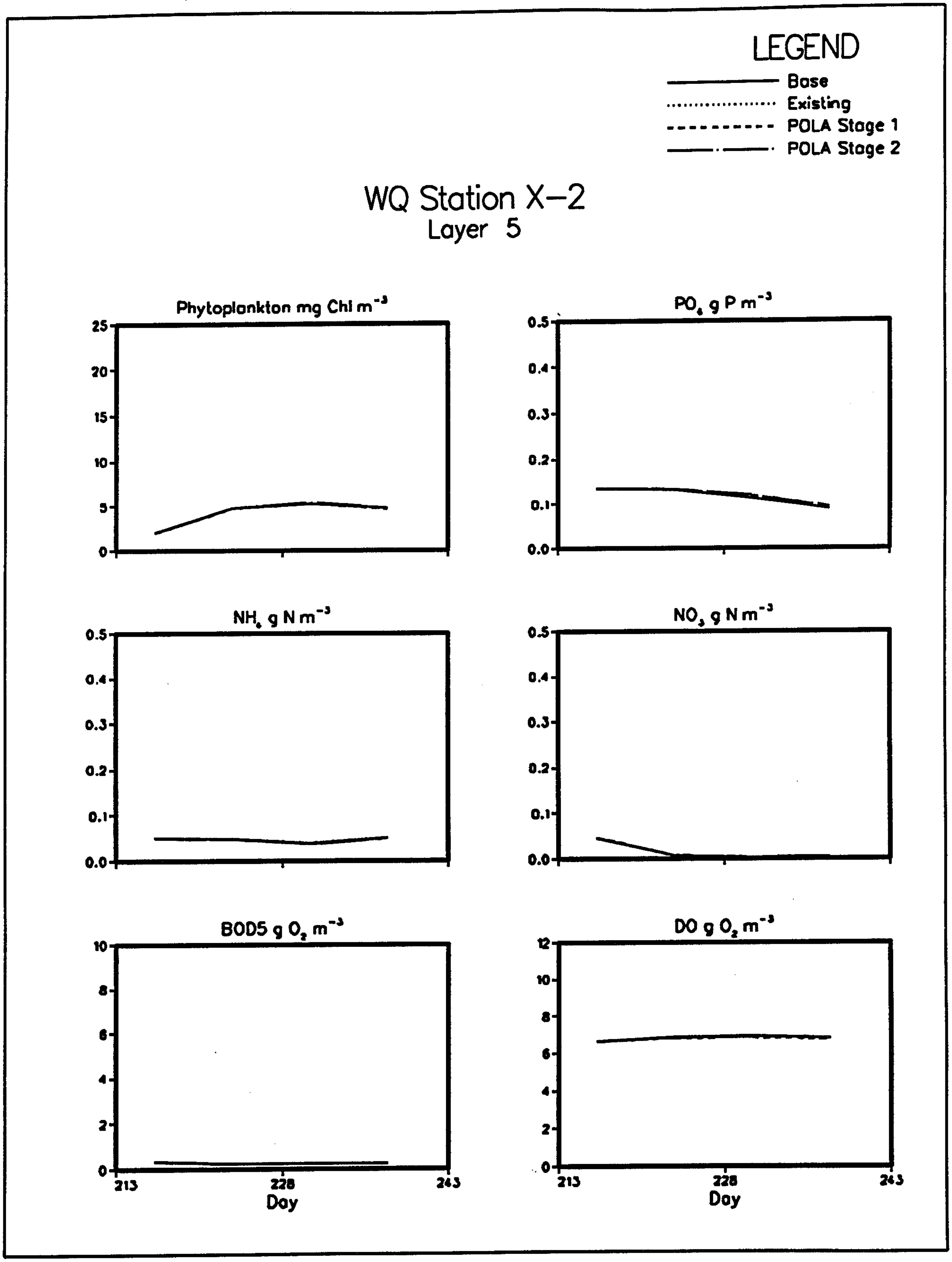
Plate B38



LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
Measured Data
WQ Station B-2
Layer 5
Phytoplankton mg Chl m-3
PO4 g P m-3
NH4 g N m-3
NO3 g N m-3
BOD5 g O2 m-3
DO g O2 m-3
213
228
243
Day

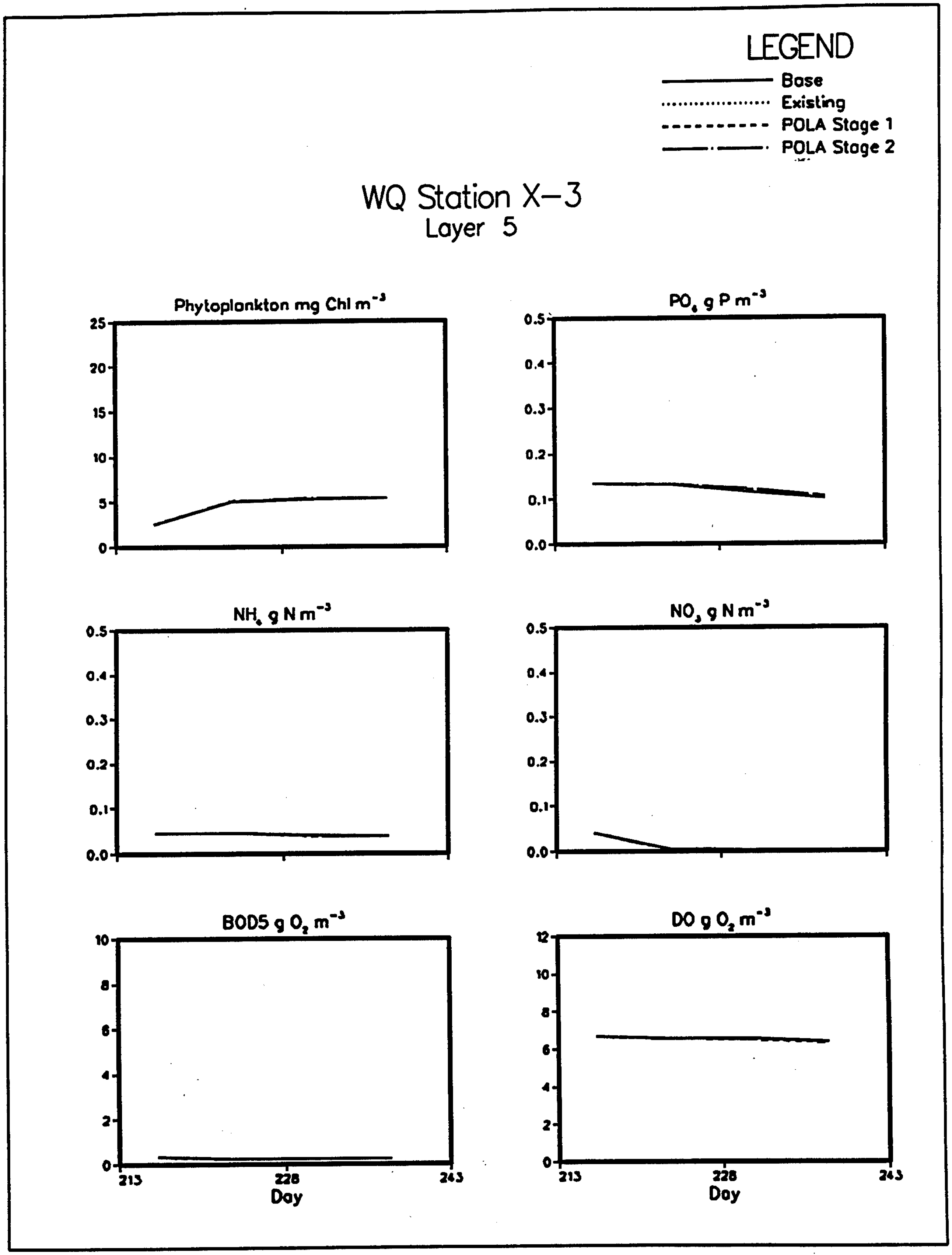

LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
Measured Data
WQ Station B-3
Layer 5
Phytoplankton mg Chl m^-3
PO4 g P m^-3
NH4 g N m^-3
NO3 g N m^-3
BOD5 g O2 m^-3
DO g O2 m^-3
213
228
243
Day
213
228
243
Day

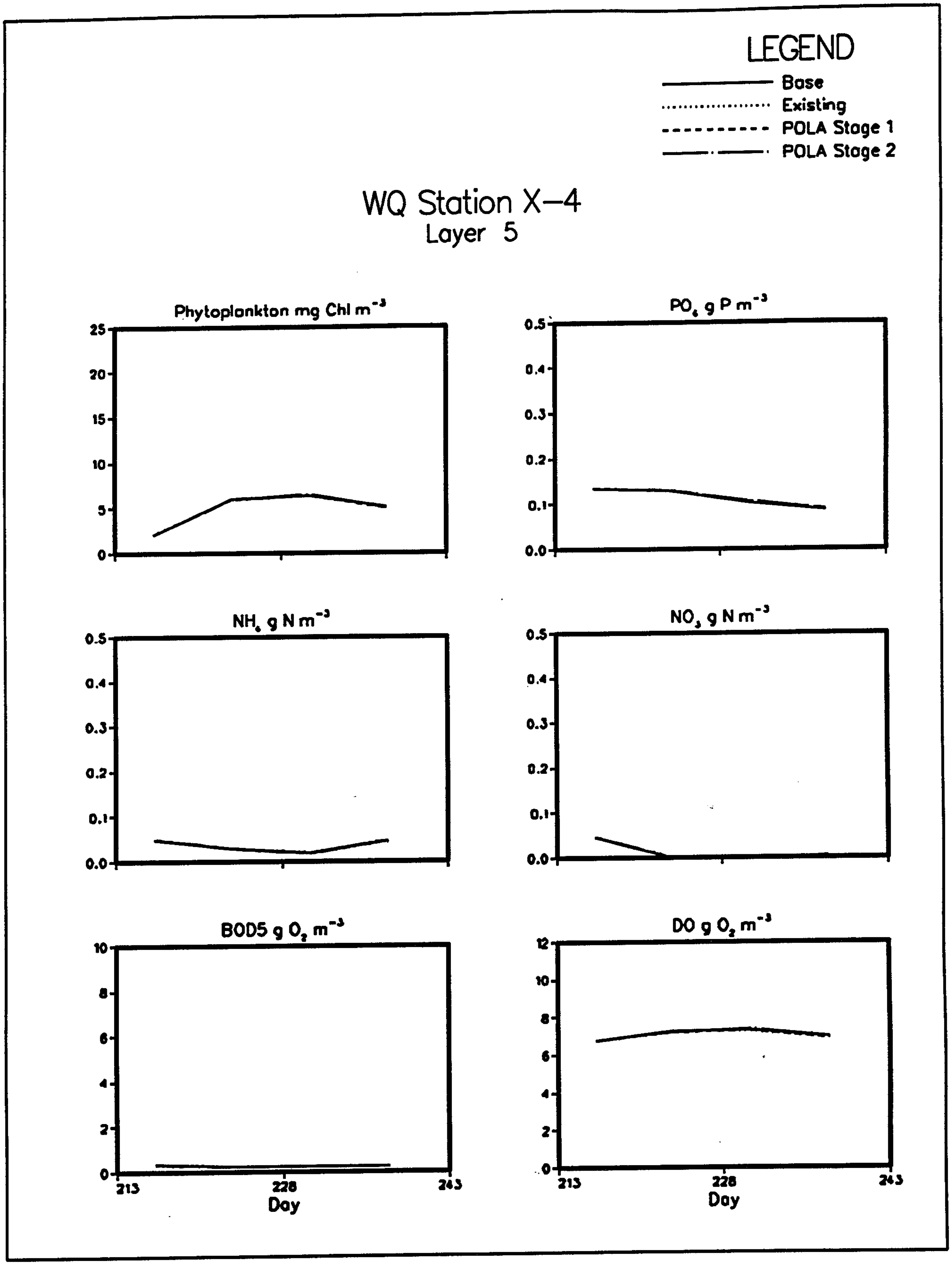

LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
WQ Station X-1
Layer 5
Phytoplankton mg Chl m^{-3}
PO_4 g P m^{-3}
NH_4 g N m^{-3}
NO_3 g N m^{-3}
BOD5 g O_2 m^{-3}
DO g O_2 m^{-3}
Day
213
228
243



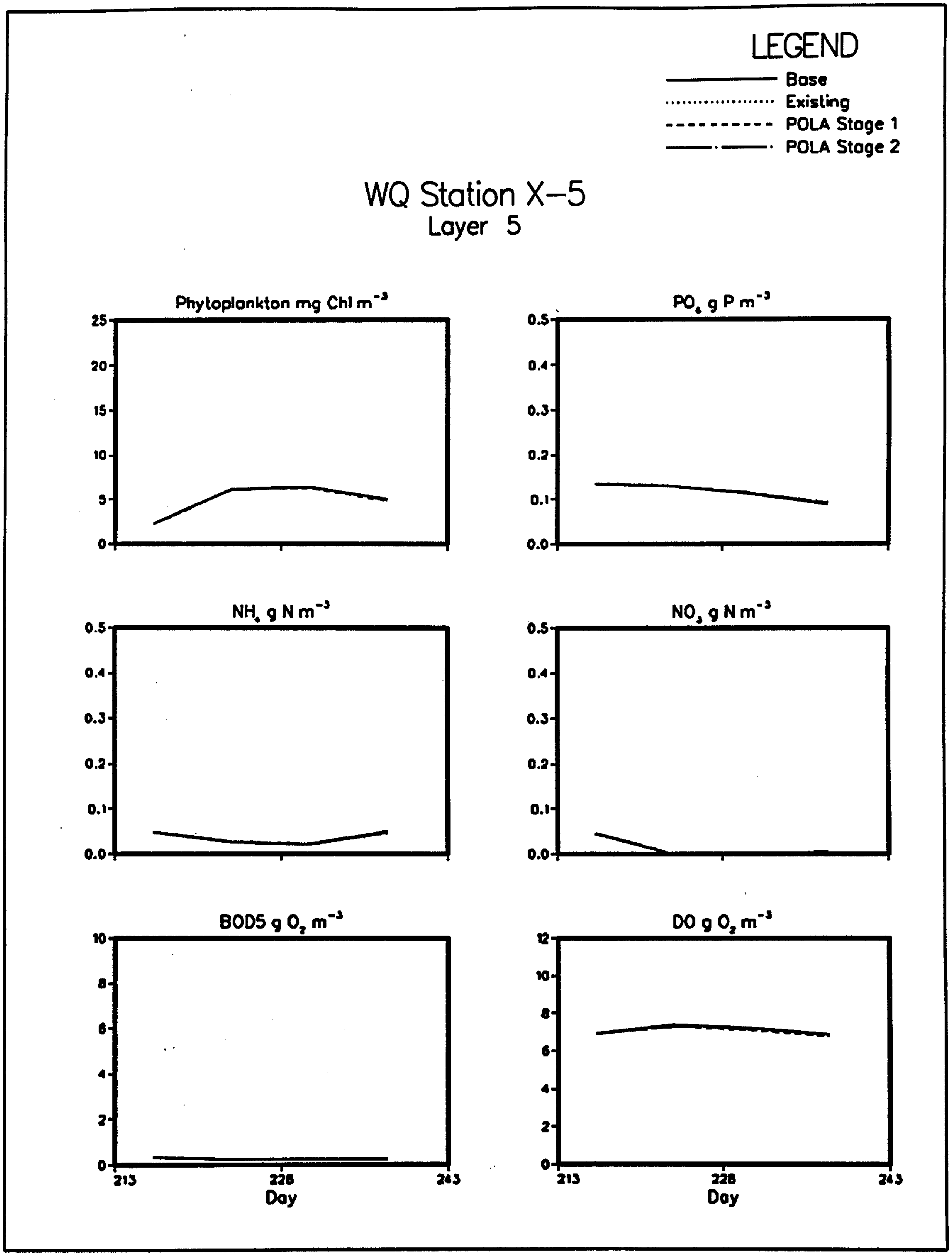
LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
WQ Station X-2
Layer 5
Phytoplankton mg Chl m-3
PO4 g P m-3
NH4 g N m-3
NO3 g N m-3
BOD5 g O2 m-3
DO g O2 m-3
213
228
243
Day

Plate B42


LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
WQ Station X-3
Layer 5
Phytoplankton mg Chl m⁻³
PO4 g P m⁻³
NH4 g N m⁻³
NO3 g N m⁻³
BOD5 g O2 m⁻³
DO g O2 m⁻³
213
228
243
Day

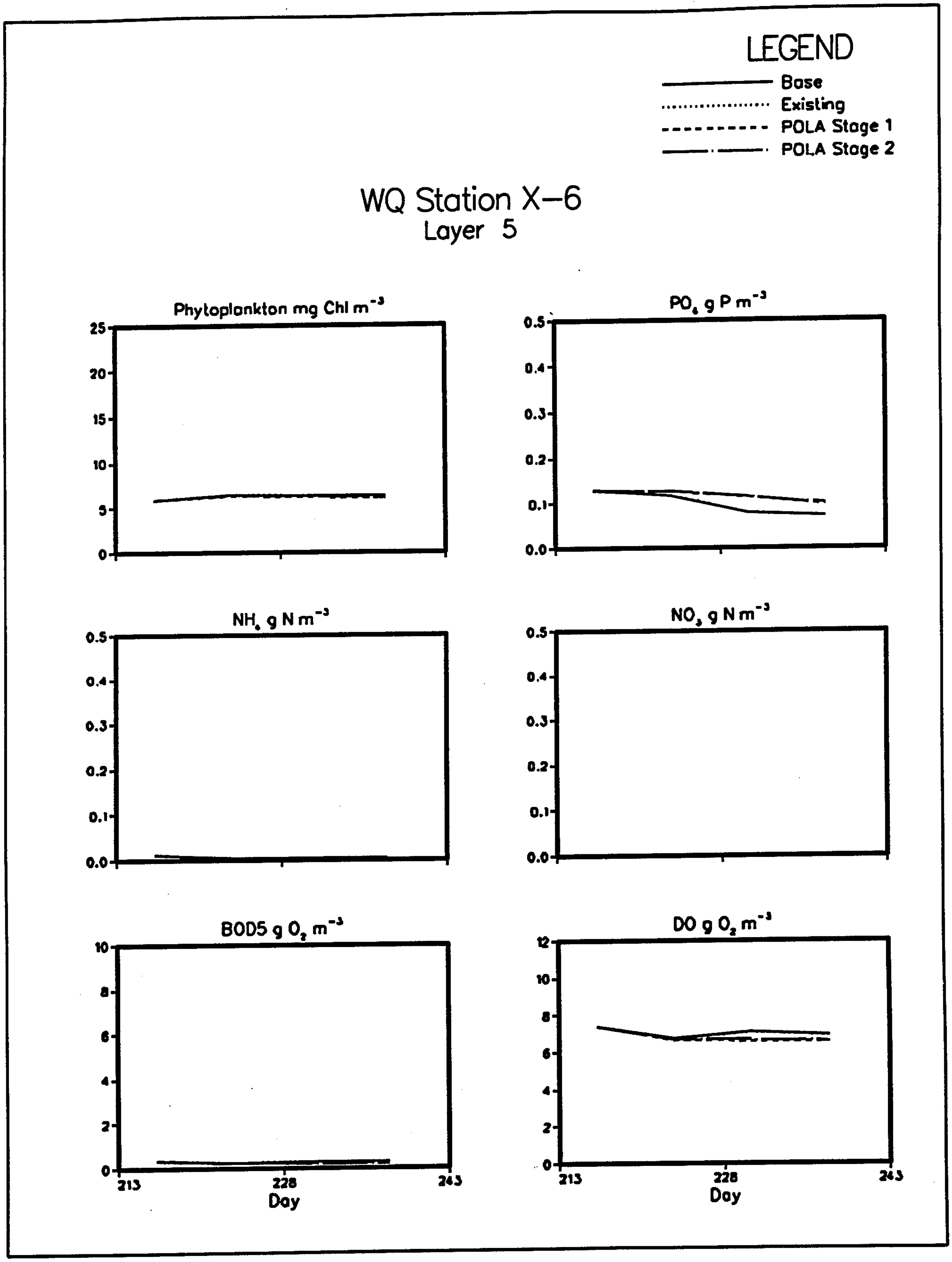


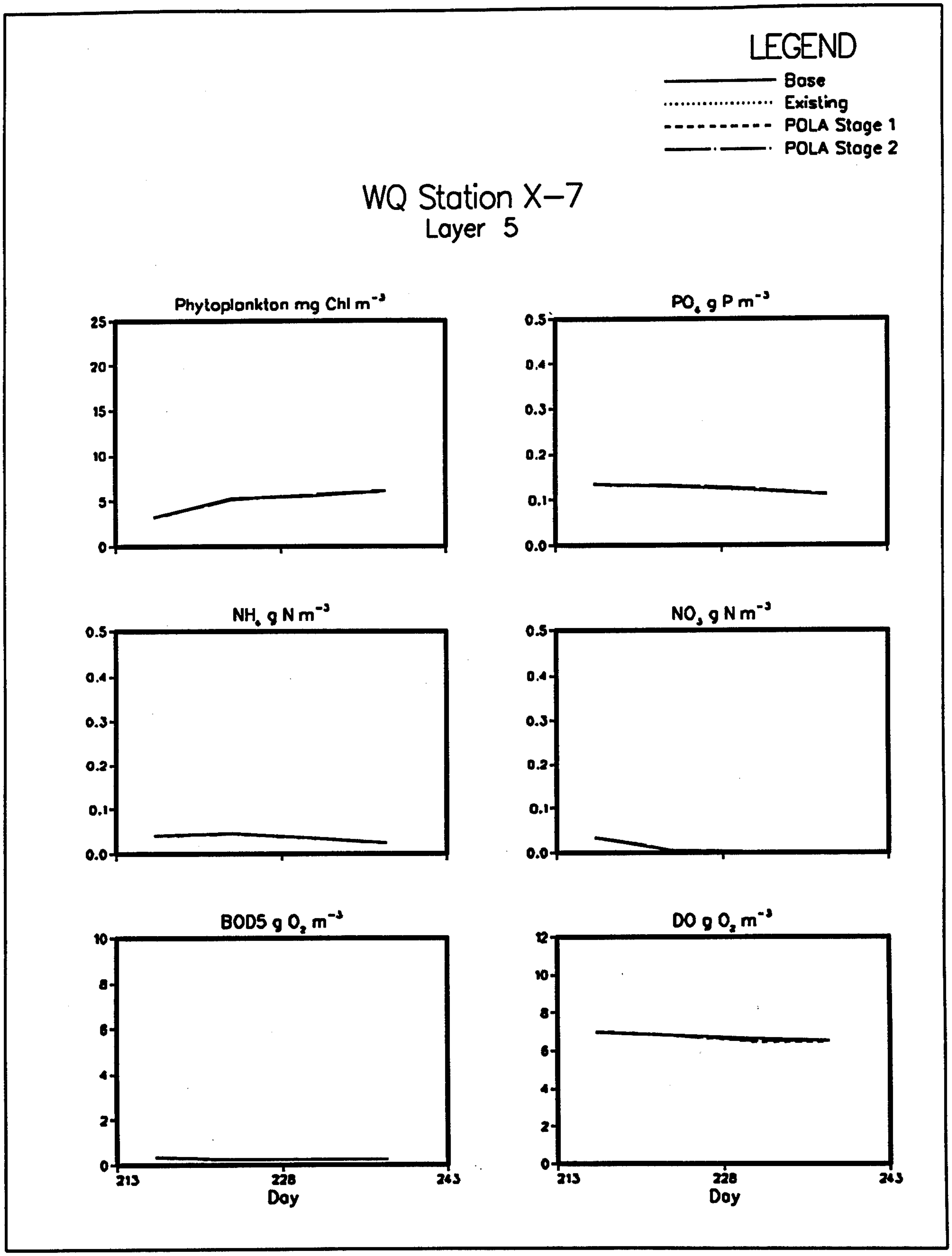
LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
WQ Station X–4
Layer 5
Phytoplankton mg Chl m^{-3}
PO_4 g P m^{-3}
NH_4 g N m^{-3}
NO_3 g N m^{-3}
BOD5 g O_2 m^{-3}
DO g O_2 m^{-3}
213
228
243
Day



LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
WQ Station X-5
Layer 5
Phytoplankton mg Chl m^-3
PO4 g P m^-3
NH4 g N m^-3
NO3 g N m^-3
BOD5 g O2 m^-3
DO g O2 m^-3
213
228
243
Day

Plate B45


LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
WQ Station X–6
Layer 5
Phytoplankton mg Chl m⁻³
PO₄ g P m⁻³
NH₄ g N m⁻³
NO₃ g N m⁻³
BOD5 g O₂ m⁻³
DO g O₂ m⁻³
213
228
243
Day


LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
WQ Station X–7
Layer 5
Phytoplankton mg Chl m⁻³
PO₄ g P m⁻³
NH₄ g N m⁻³
NO₃ g N m⁻³
BOD5 g O₂ m⁻³
DO g O₂ m⁻³
Day
Day

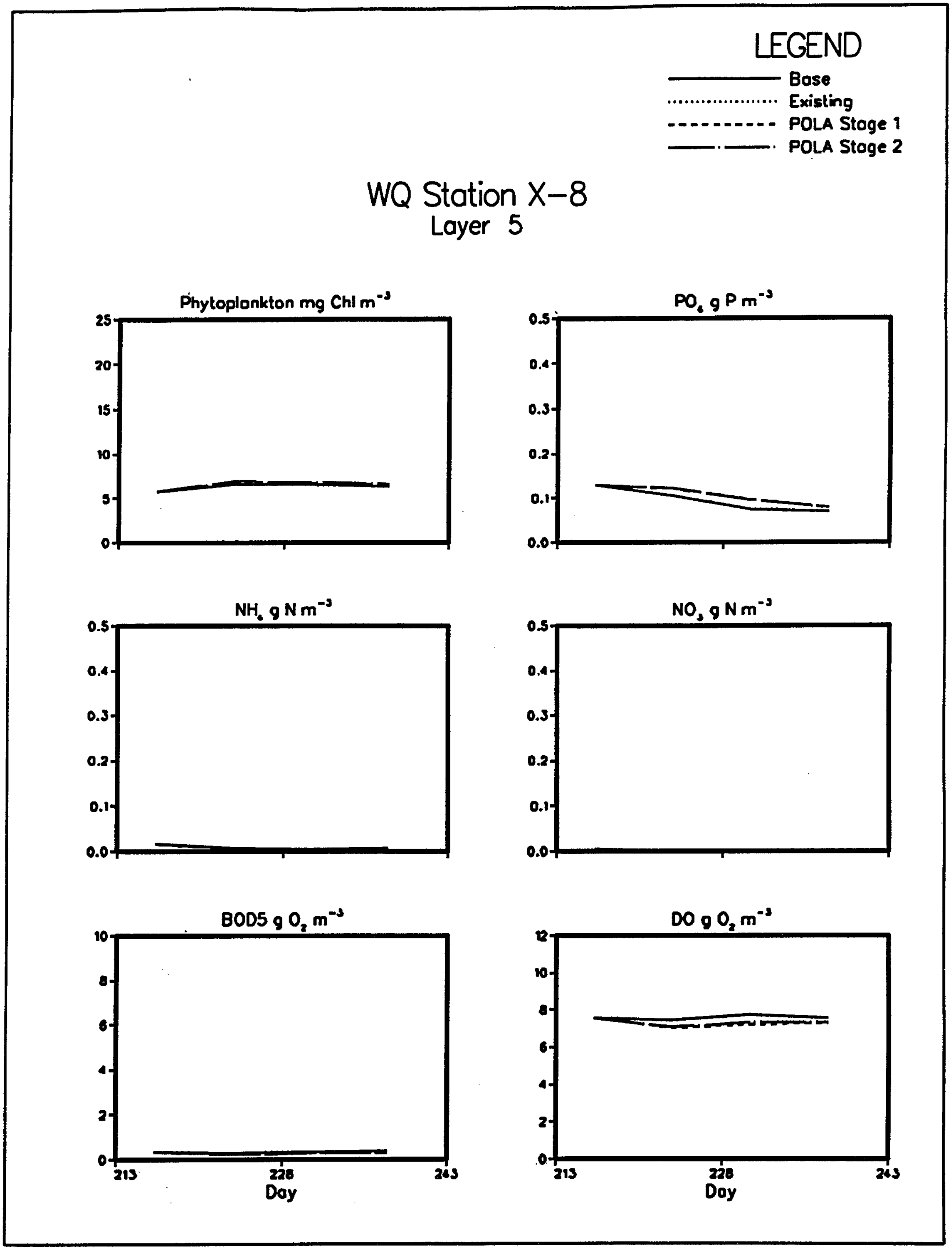
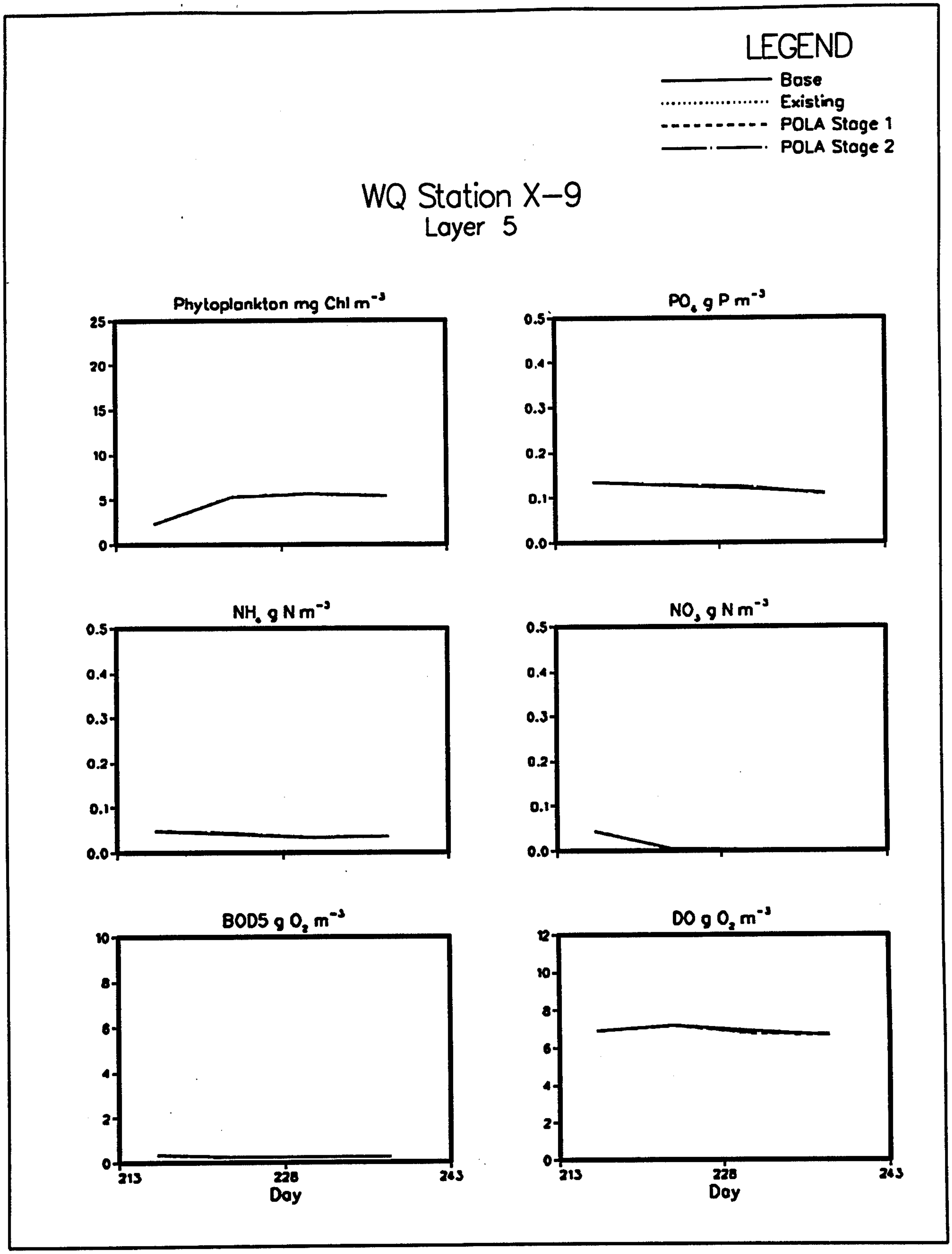
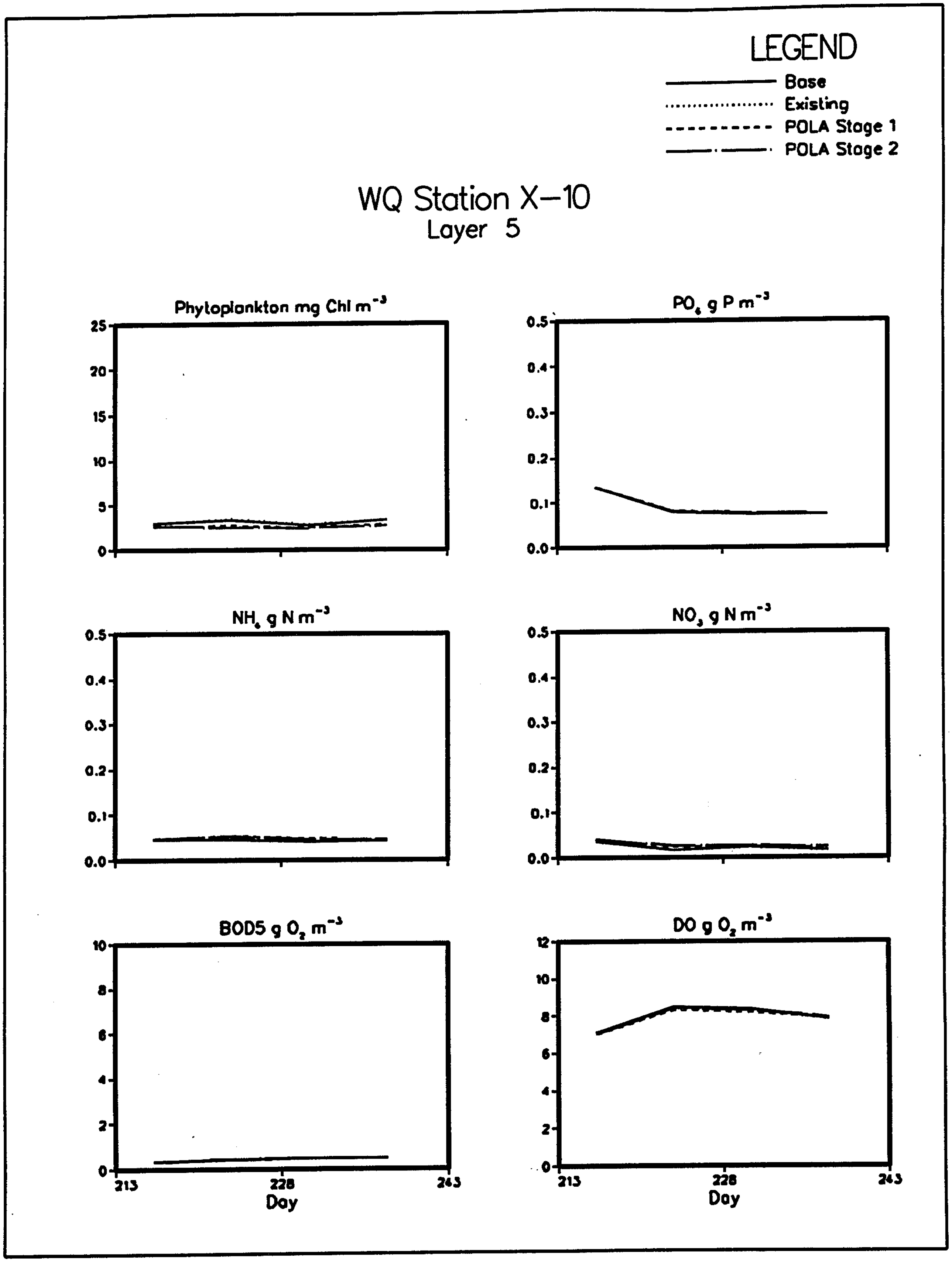
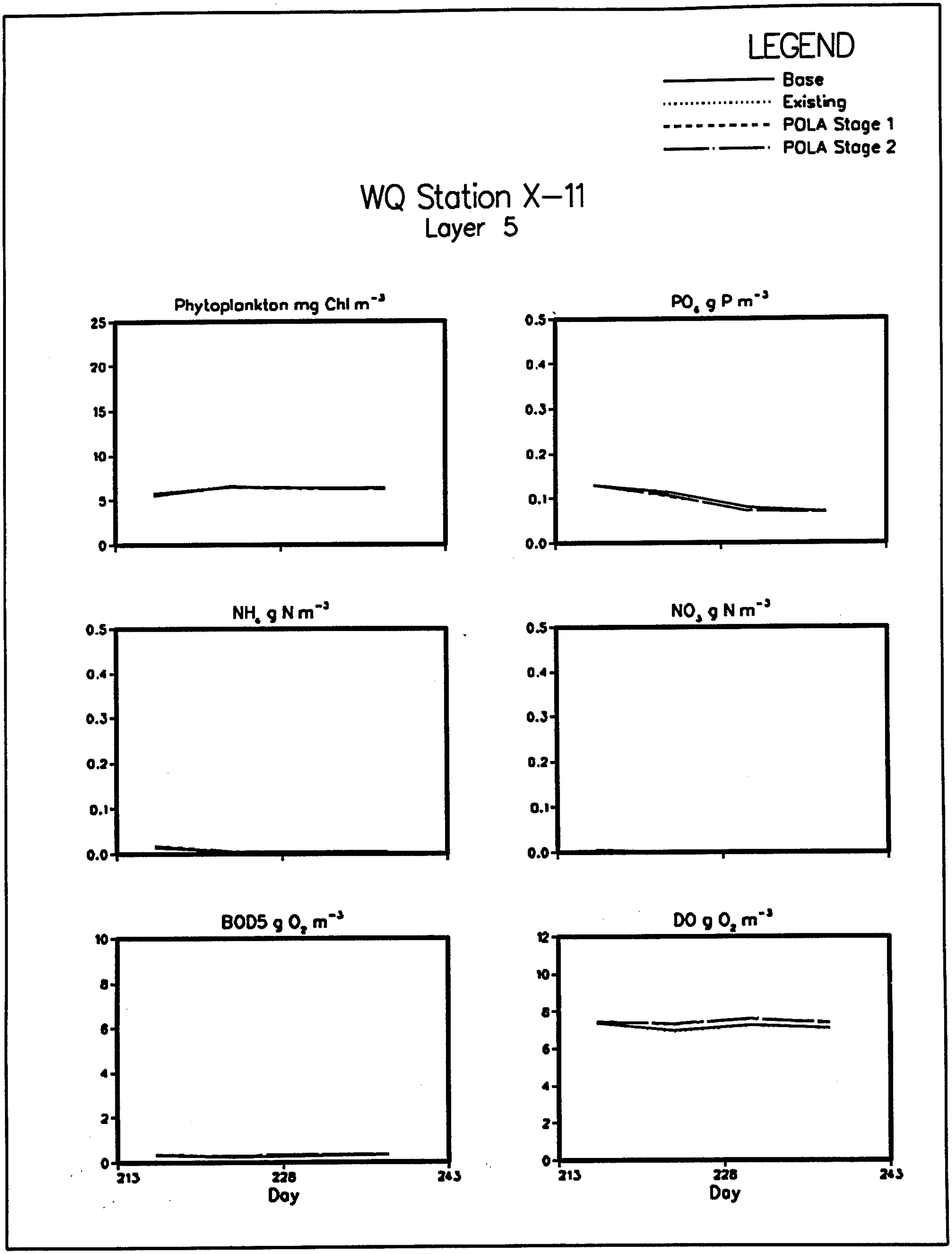

LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
WQ Station X-8
Layer 5
Phytoplankton mg Chl m-3
PO4 g P m-3
NH4 g N m-3
NO3 g N m-3
BOD5 g O2 m-3
DO g O2 m-3
213
228
243
Day

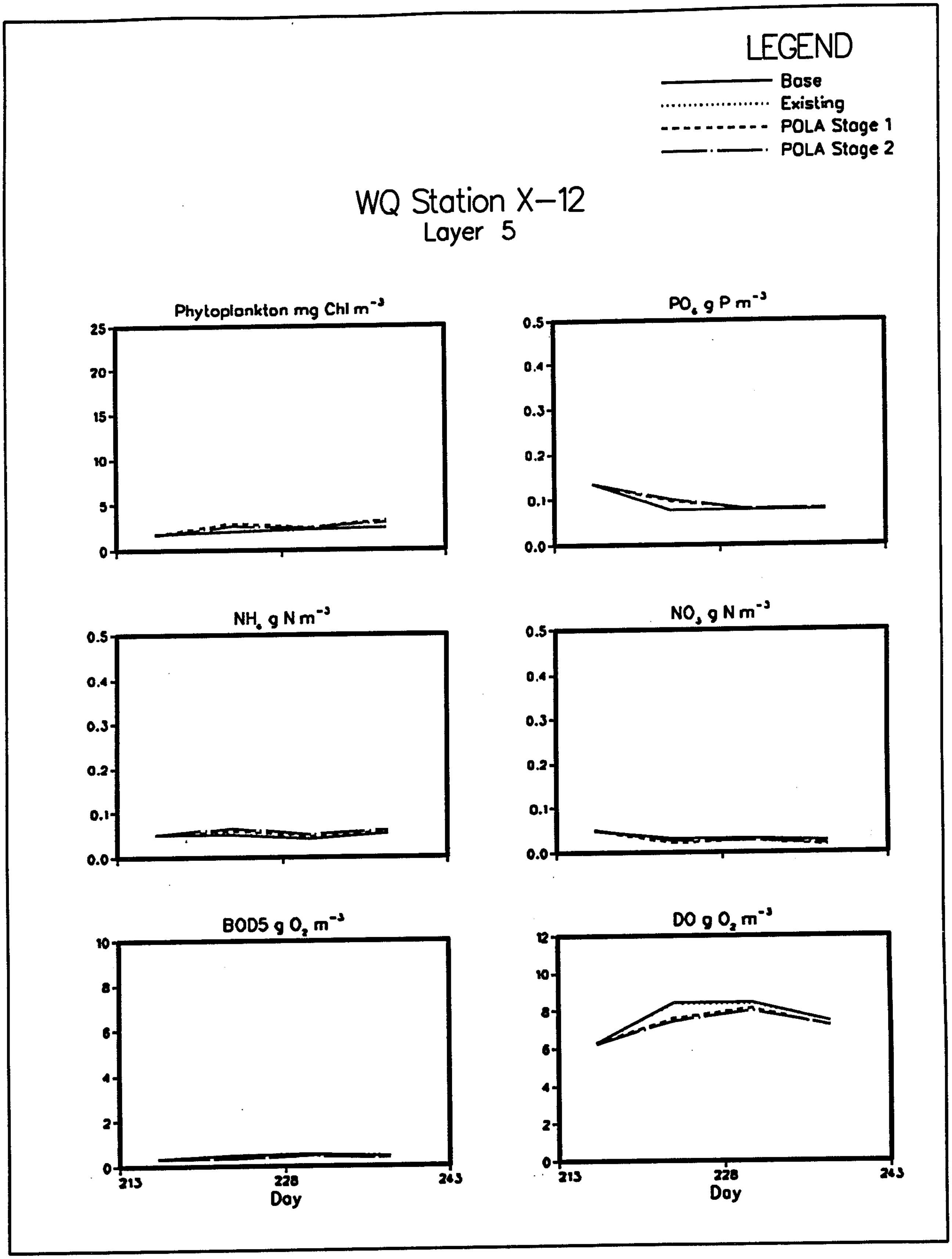
Plate B48



LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
WQ Station X-9
Layer 5
Phytoplankton mg Chl m^-3
PO_4 g P m^-3
NH_4 g N m^-3
NO_3 g N m^-3
BOD5 g O_2 m^-3
DO g O_2 m^-3
Day
213
228
243


LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
WQ Station X-10
Layer 5
Phytoplankton mg Chl m-3
PO4 g P m-3
NH4 g N m-3
NO3 g N m-3
BOD5 g O2 m-3
DO g O2 m-3
213
228
243
Day


LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
WQ Station X-11
Layer 5
Phytoplankton mg Chl m-3
PO4 g P m-3
NH4 g N m-3
NO3 g N m-3
BOD5 g O2 m-3
DO g O2 m-3
213
228
243
Day



LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
WQ Station X-12
Layer 5
Phytoplankton mg Chl m-3
PO4 g P m-3
NH4 g N m-3
NO3 g N m-3
BOD5 g O2 m-3
DO g O2 m-3
213
228
243
Day

Plate B52

Appendix C
Vertical Profile Plots

Plate	Plot
C1	Station I-01, Date 216.5
C2	Station I-02, Date 216.5
C3	Station I-07, Date 216.5
C4	Station X-11, Date 216.5
C5	Station X-12, Date 216.5
C6	Station I-01, Date 223.5
C7	Station I-02, Date 223.5
C8	Station I-07, Date 223.5
C9	Station X-11, Date 223.5
C10	Station X-12, Date 223.5
C11	Station I-01, Date 230.5
C12	Station I-02, Date 230.5
C13	Station I-07, Date 230.5
C14	Station X-11, Date 230.5
C15	Station X-12, Date 230.5
C16	Station I-01, Date 237.5
C17	Station I-02, Date 237.5
C18	Station I-07, Date 237.5
C19	Station X-11, Date 237.5
C20	Station X-12, Date 237.5

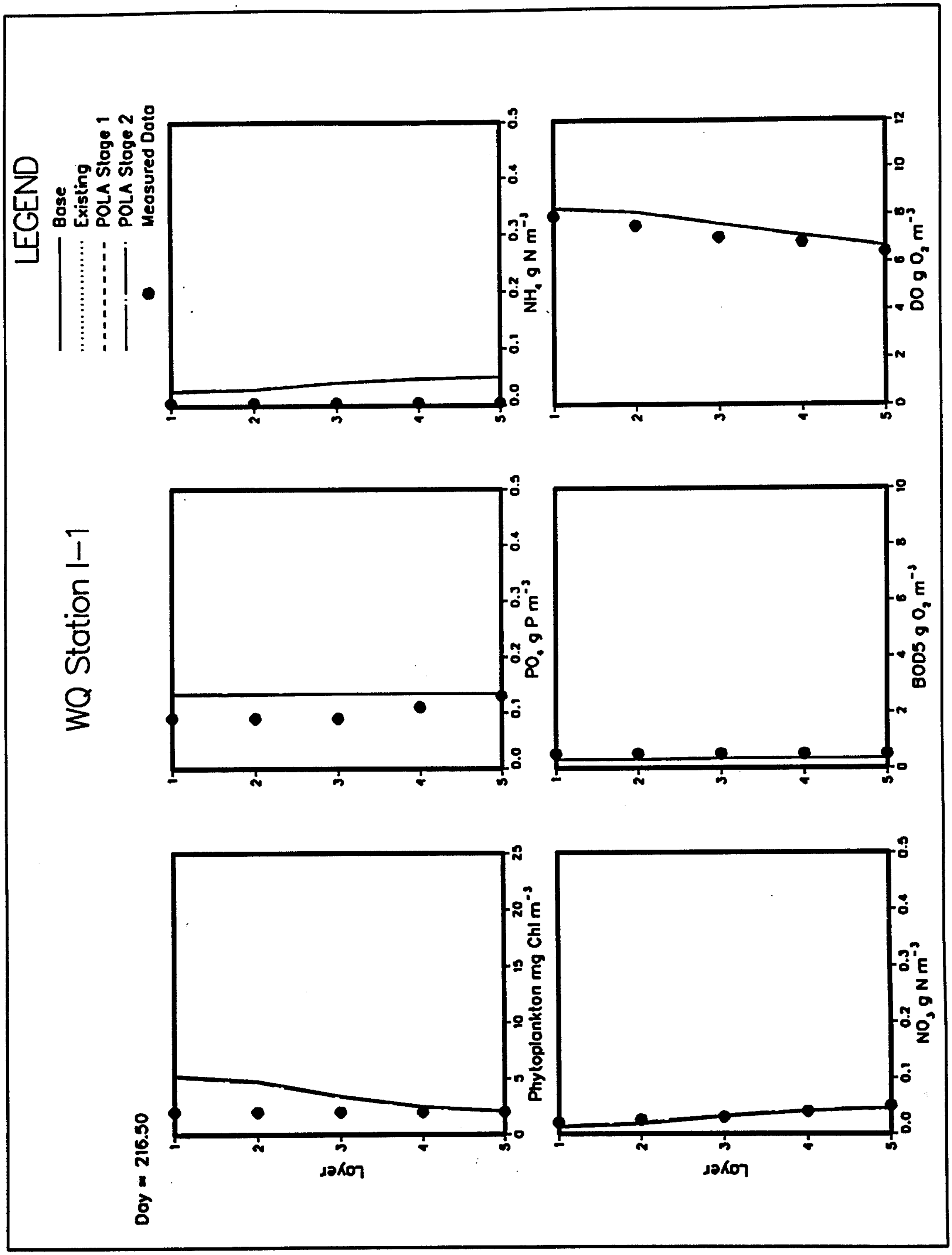

WQ Station I-1
LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
Measured Data
Day = 216.50
Layer
Phytoplankton mg Chl m-3
PO4 g P m-3
NH4 g N m-3
NO3 g N m-3
BOD5 g O2 m-3
DO g O2 m-3

Plate C1

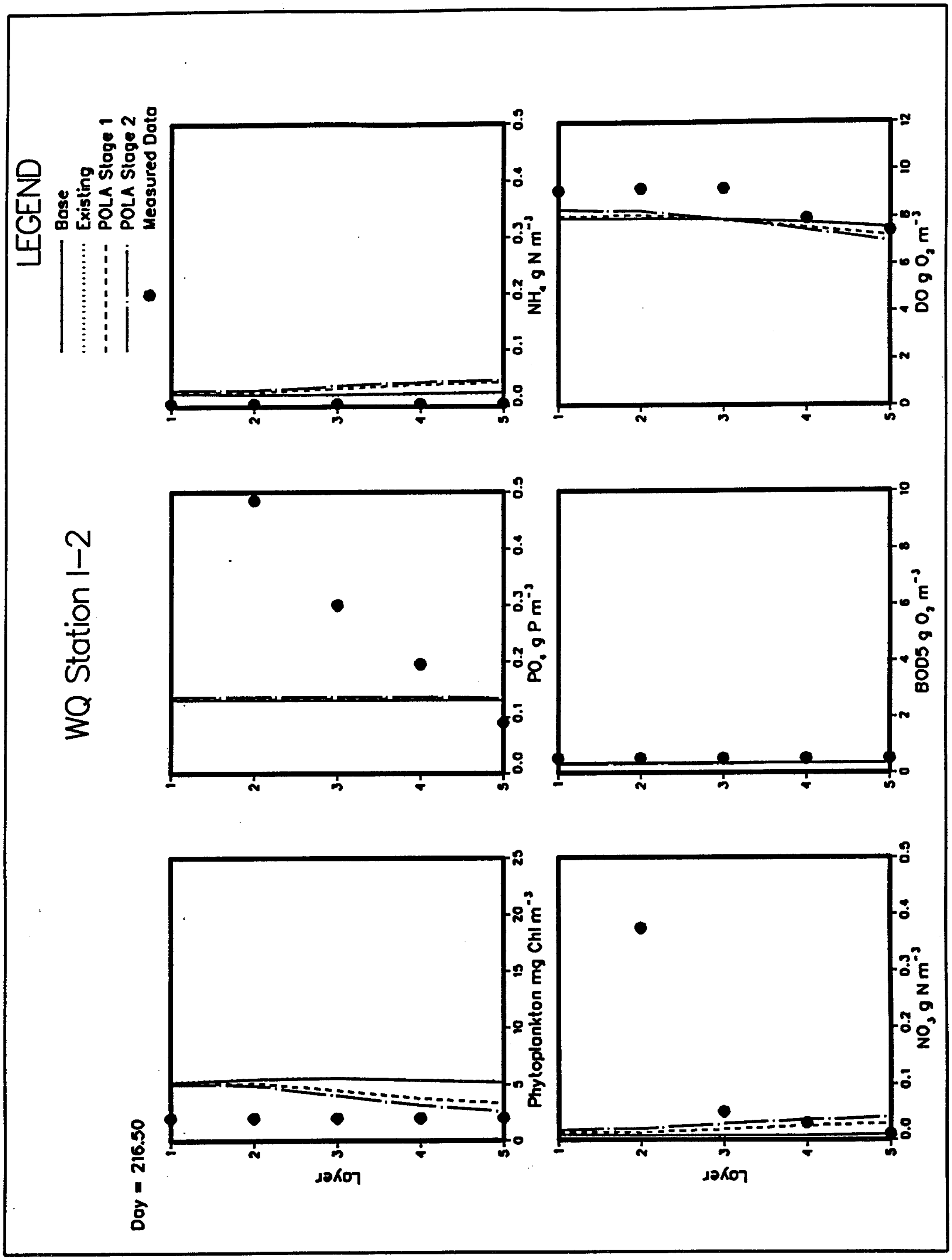

WQ Station I-2
LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
Measured Data
Day = 216.50
Layer
Phytoplankton mg Chl m^{-3}
PO$_4$ g P m^{-3}
NH$_4$ g N m^{-3}
Layer
NO$_3$ g N m^{-3}
BOD5 g O$_2$ m^{-3}
DO g O$_2$ m^{-3}

Plate C2

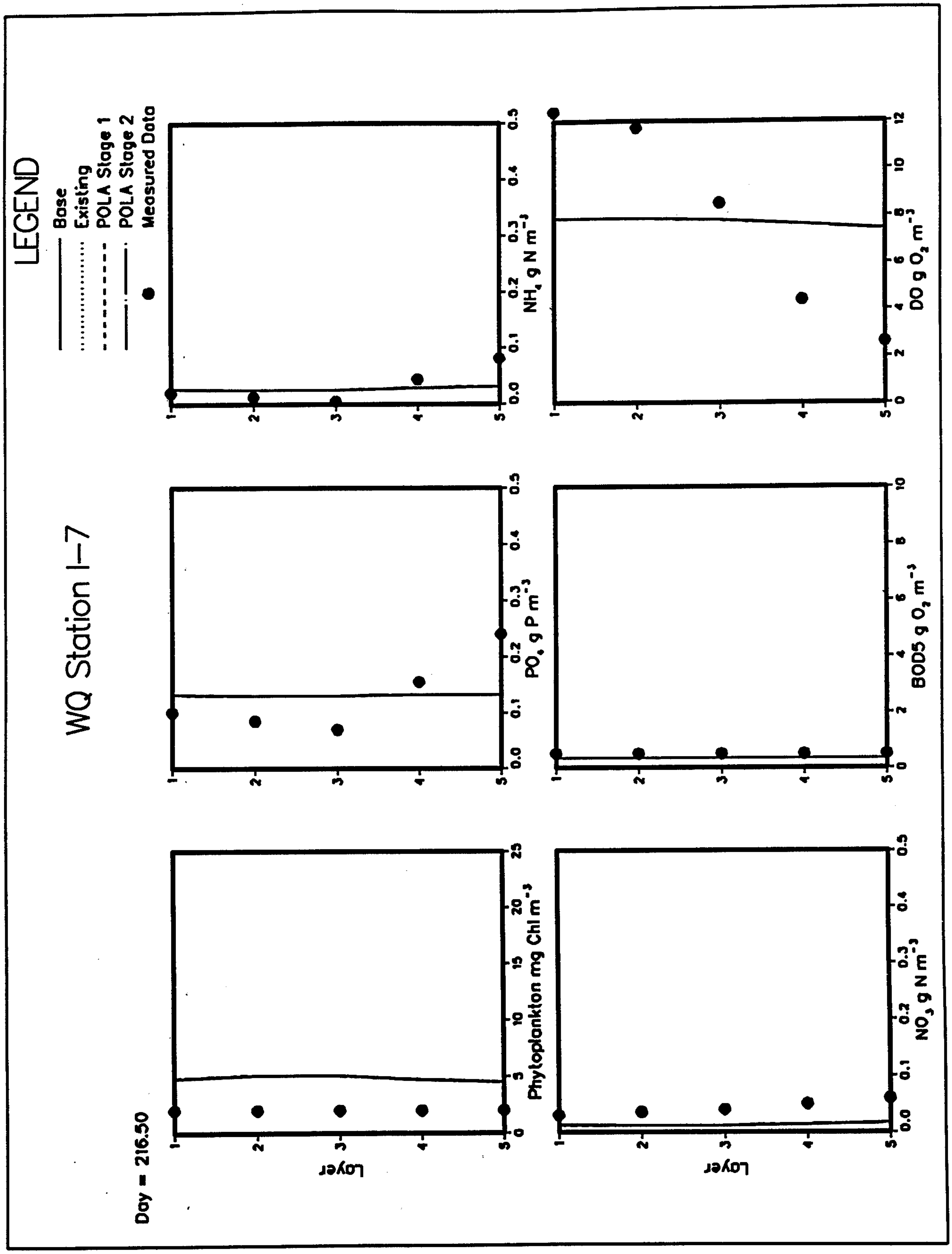
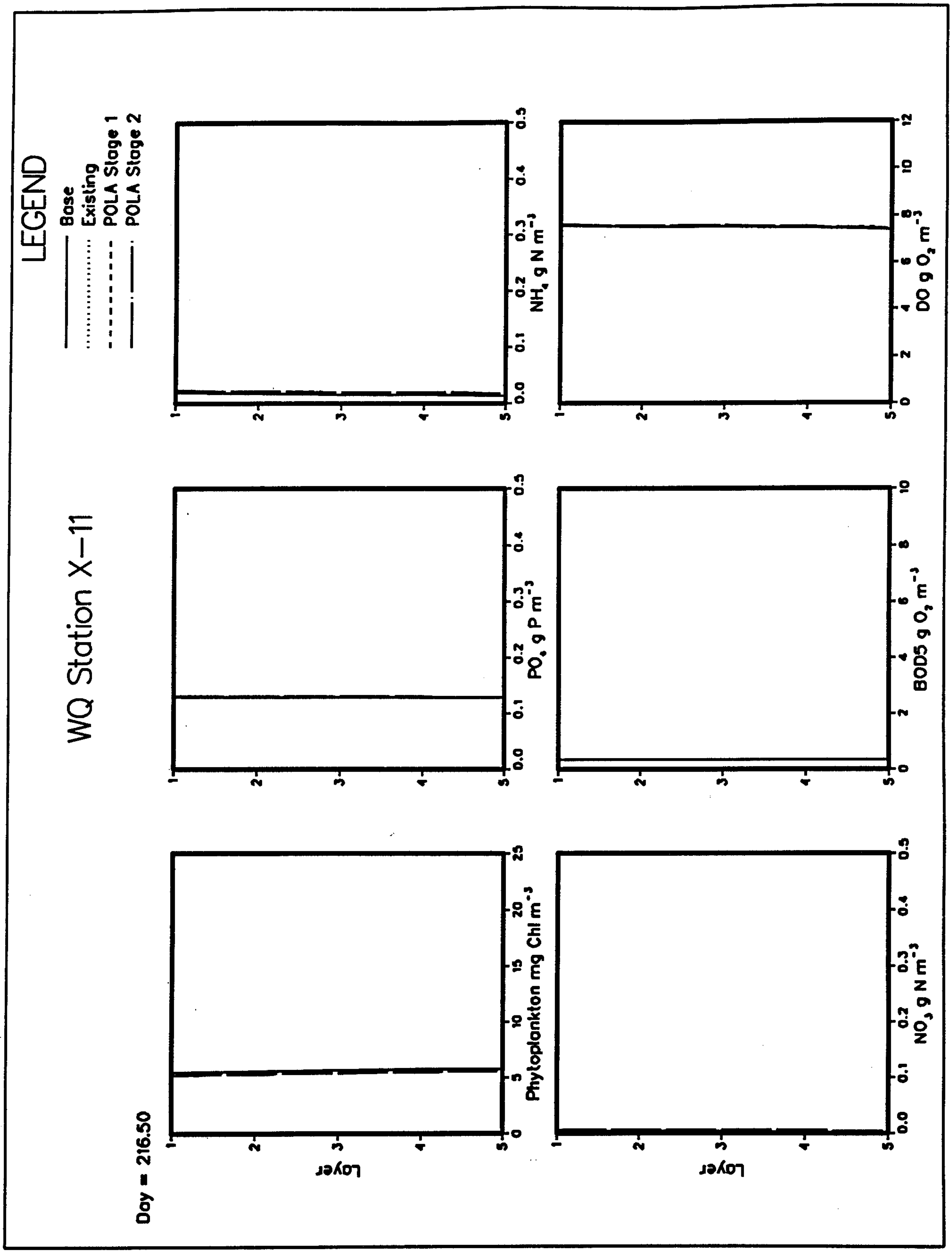

LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
Measured Data
WQ Station I-7
Day = 216.50
Layer
Phytoplankton mg Chl m-3
PO4 g P m-3
NH4 g N m-3
NO3 g N m-3
BOD5 g O2 m-3
DO g O2 m-3

Plate C3



WQ Station X–11
LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
Day = 216.50
Layer
Phytoplankton mg Chl m^-3
PO4 g P m^-3
NH4 g N m^-3
NO3 g N m^-3
BOD5 g O2 m^-3
DO g O2 m^-3

Plate C4

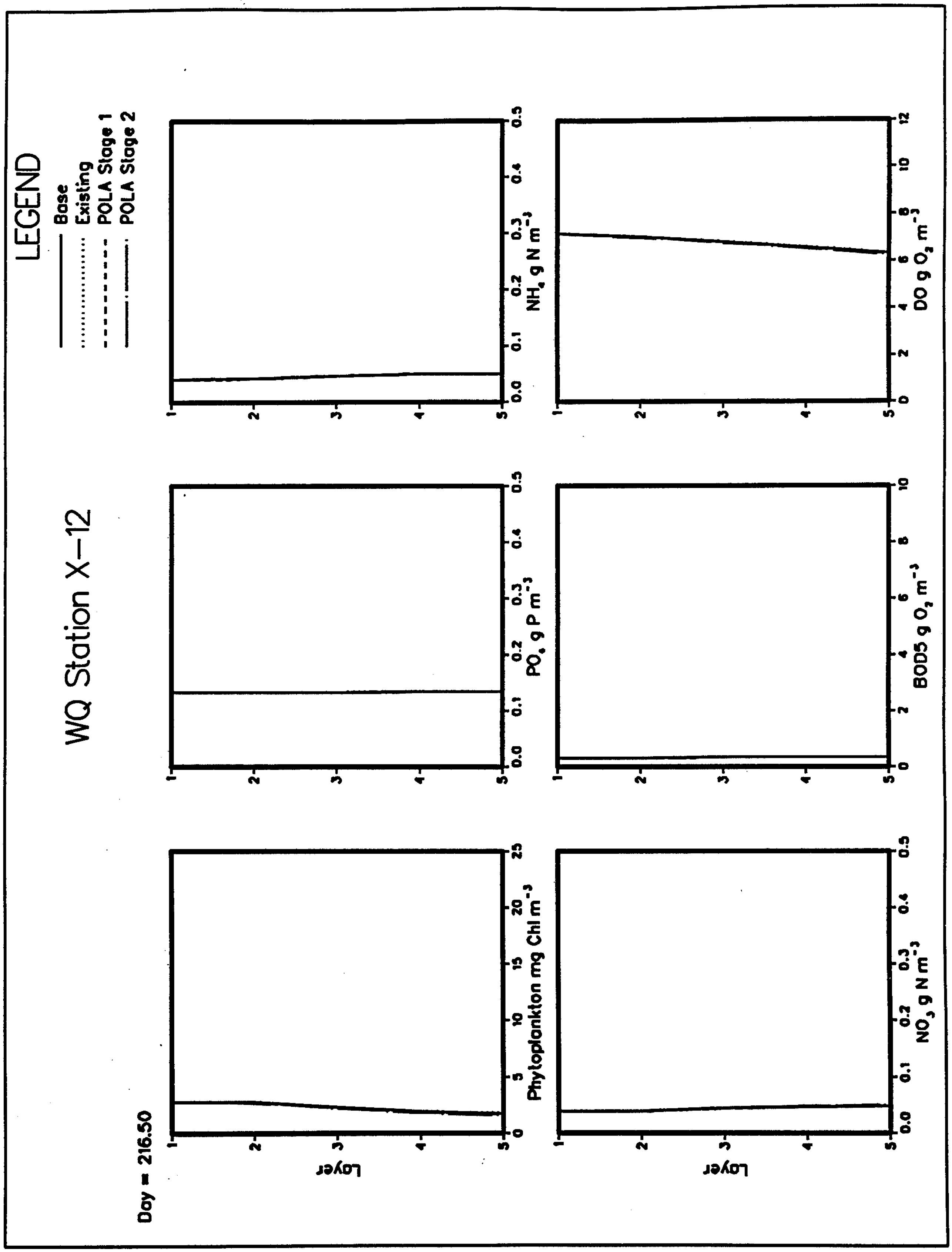

WQ Station X–12
LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
Day = 216.50
Layer
Phytoplankton mg Chl m^{-3}
PO_4 g P m^{-3}
NH_4 g N m^{-3}
NO_3 g N m^{-3}
BOD5 g O_2 m^{-3}
DO g O_2 m^{-3}

Plate C5

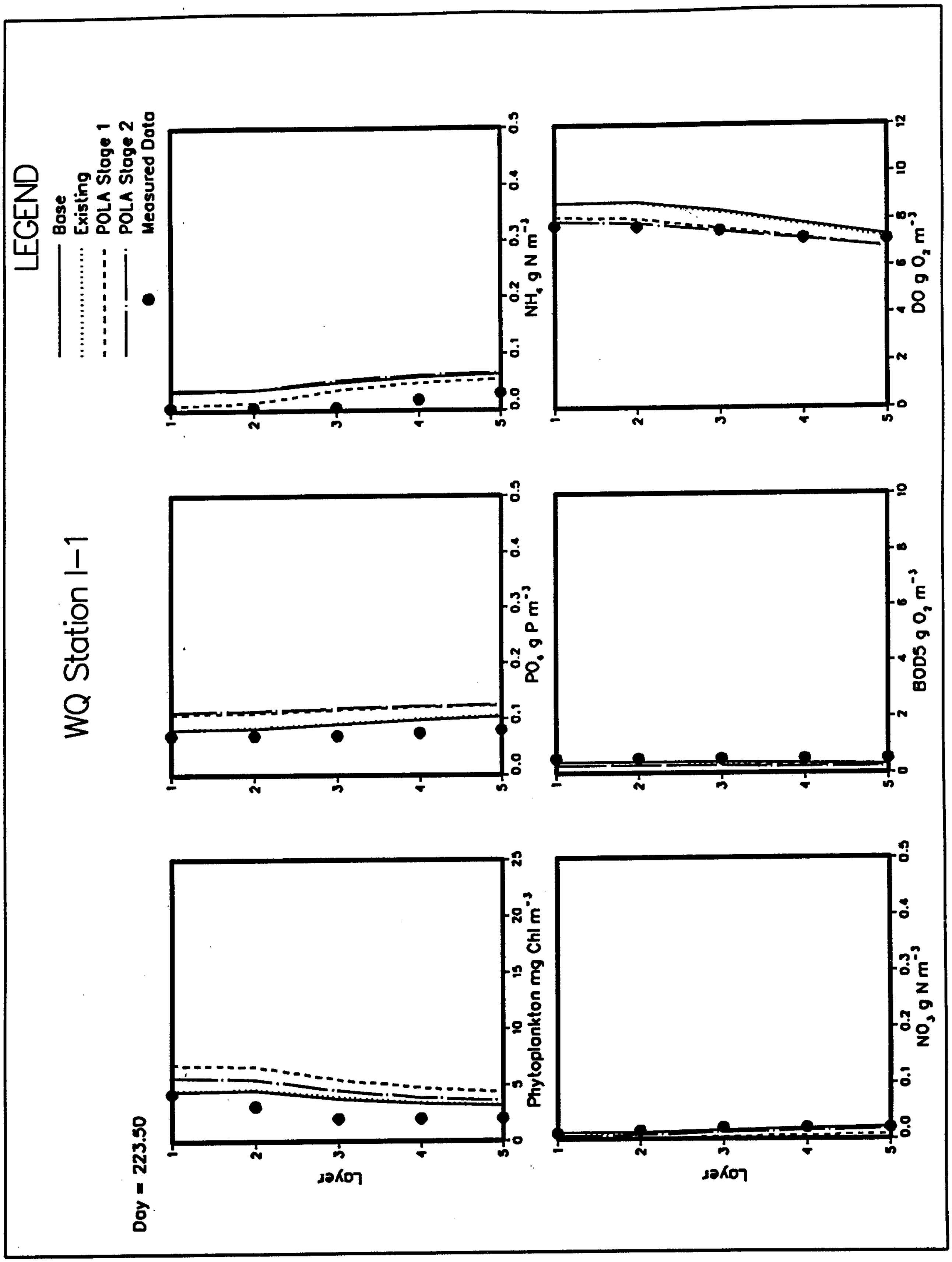
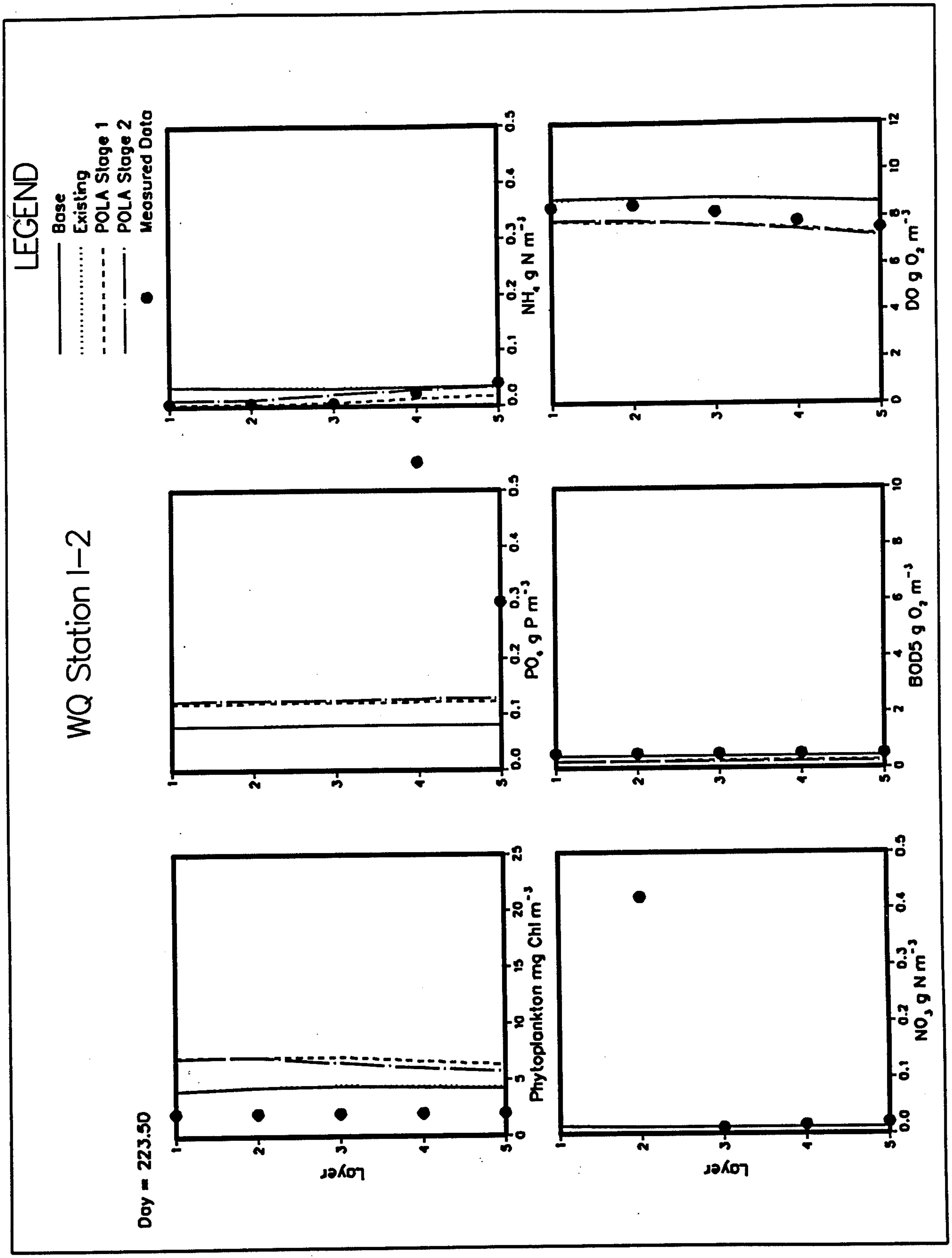

WQ Station I-1
LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
Measured Data
Day = 223.50
Layer
Phytoplankton mg Chl m-3
PO4 g P m-3
NH4 g N m-3
NO3 g N m-3
BOD5 g O2 m-3
DO g O2 m-3

Plate C6



WQ Station I-2
Day = 223.50
LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
Measured Data
Layer
Phytoplankton mg Chl m^{-3}
PO_4 g P m^{-3}
NH_4 g N m^{-3}
NO_3 g N m^{-3}
BOD5 g O_2 m^{-3}
DO g O_2 m^{-3}

Plate C7

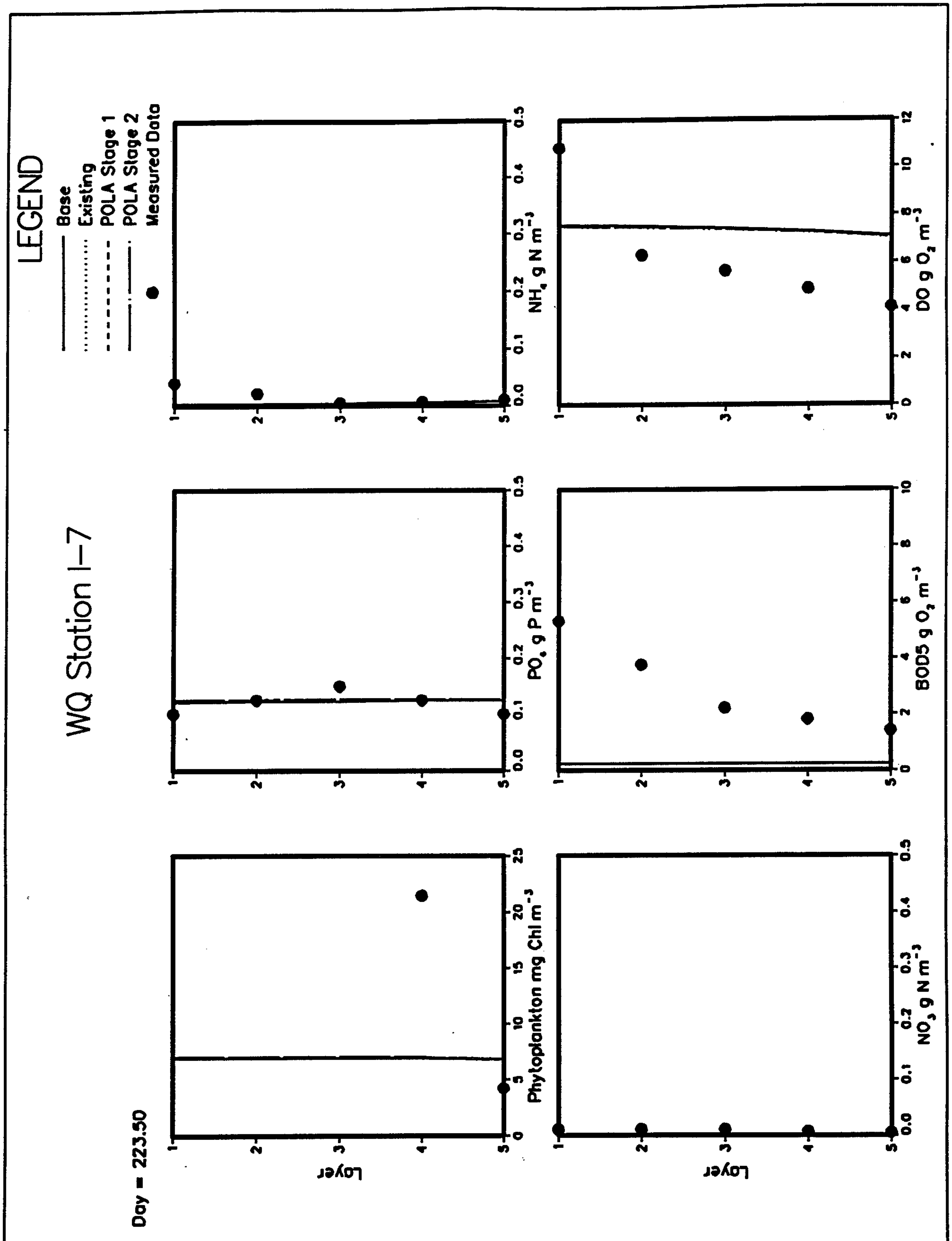
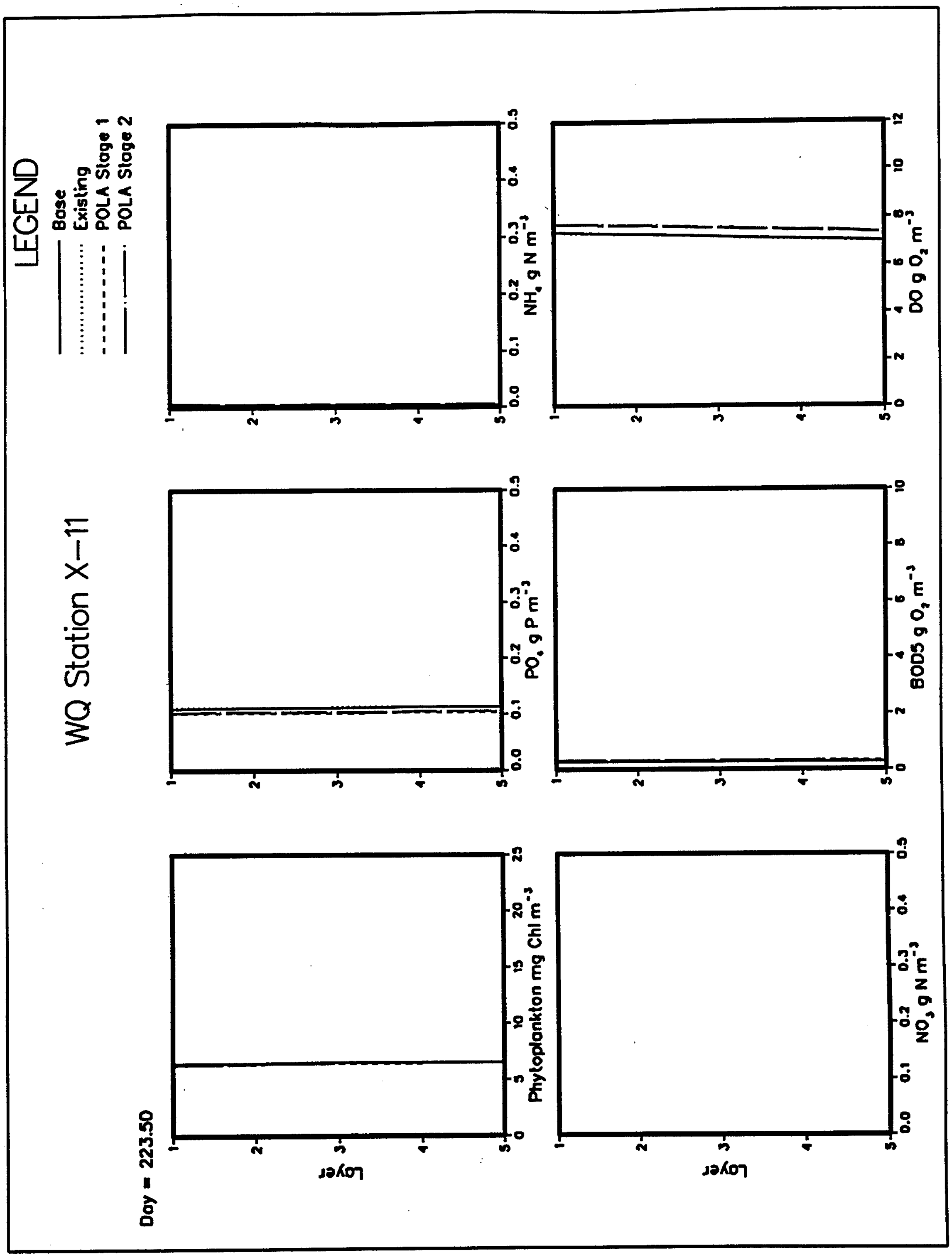

WQ Station I-7
Day = 223.50
LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
Measured Data
Layer
Phytoplankton mg Chl m^-3
PO_4 g P m^-3
NH_4 g N m^-3
NO_3 g N m^-3
BOD5 g O_2 m^-3
DO g O_2 m^-3

Plate C8


WQ Station X–11
LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
Day = 223.50
Layer
Phytoplankton mg Chl m-3
PO4 g P m-3
NH4 g N m-3
NO3 g N m-3
BOD5 g O2 m-3
DO g O2 m-3

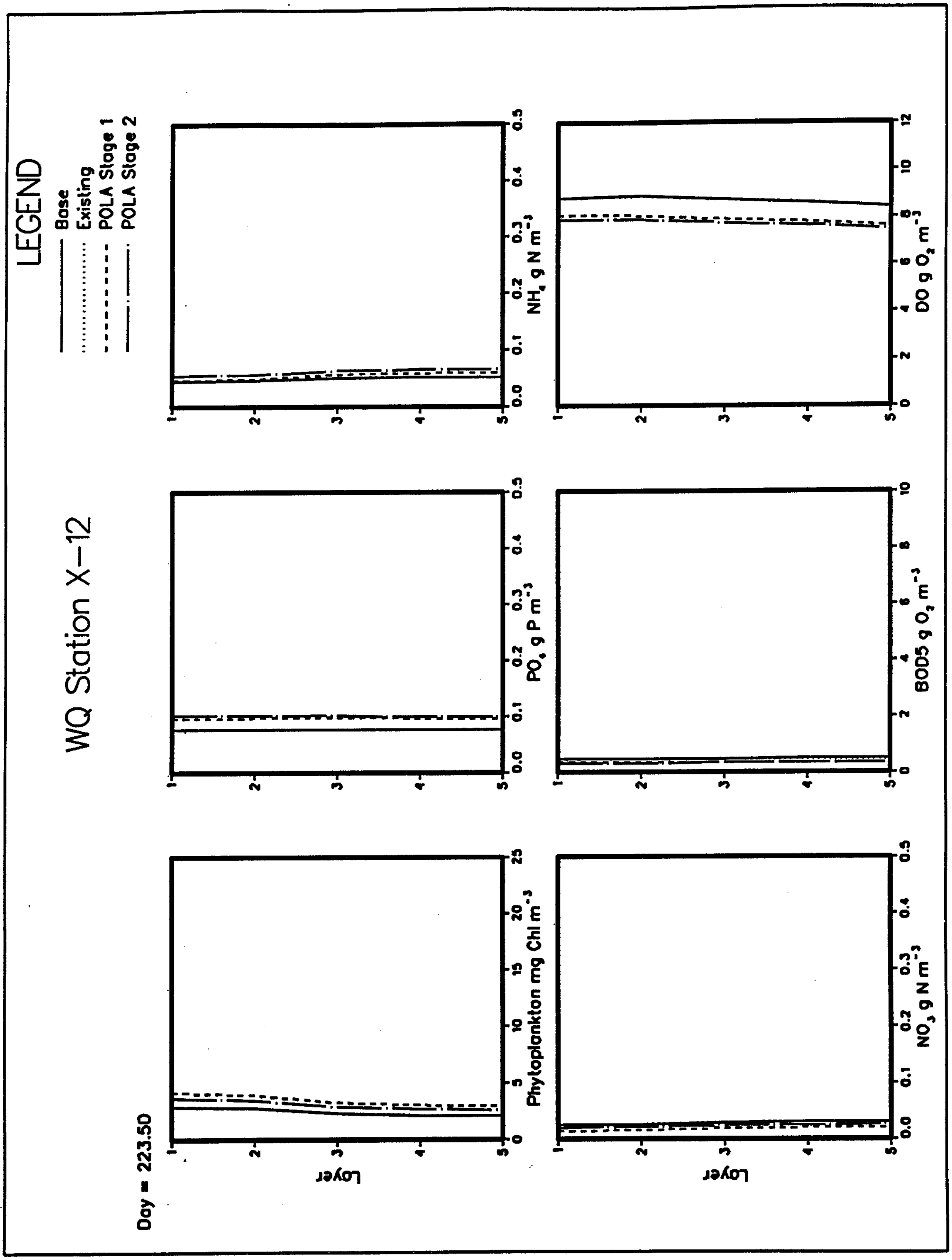
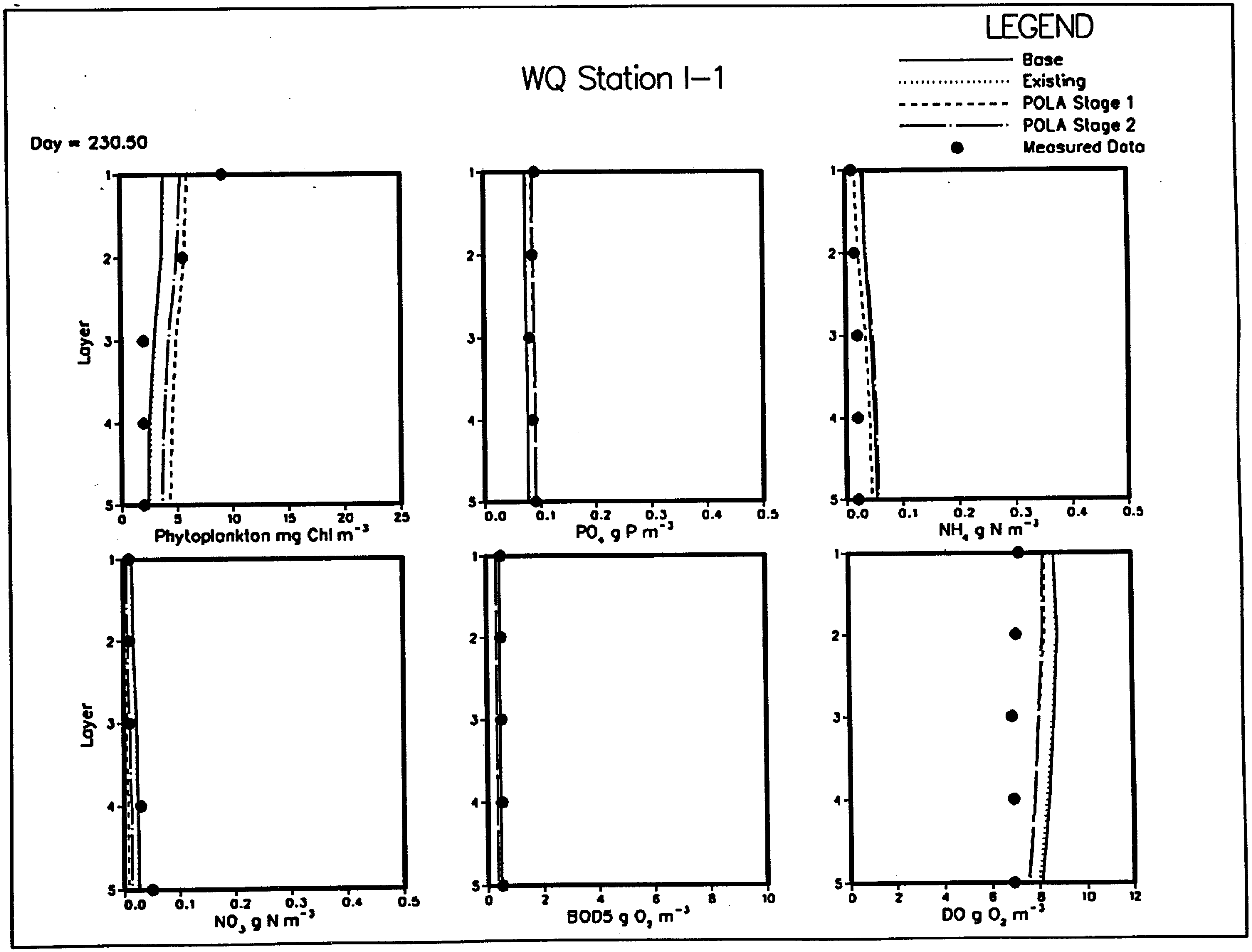

WQ Station X–12
LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
Day = 223.50
Layer
Layer
Phytoplankton mg Chl m^-3
PO4 g P m^-3
NH4 g N m^-3
NO3 g N m^-3
BOD5 g O2 m^-3
DO g O2 m^-3

Plate C10


WQ Station I-1
LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
Measured Data
Day = 230.50
Layer
Phytoplankton mg Chl m^-3
PO4 g P m^-3
NH4 g N m^-3
NO3 g N m^-3
BOD5 g O2 m^-3
DO g O2 m^-3

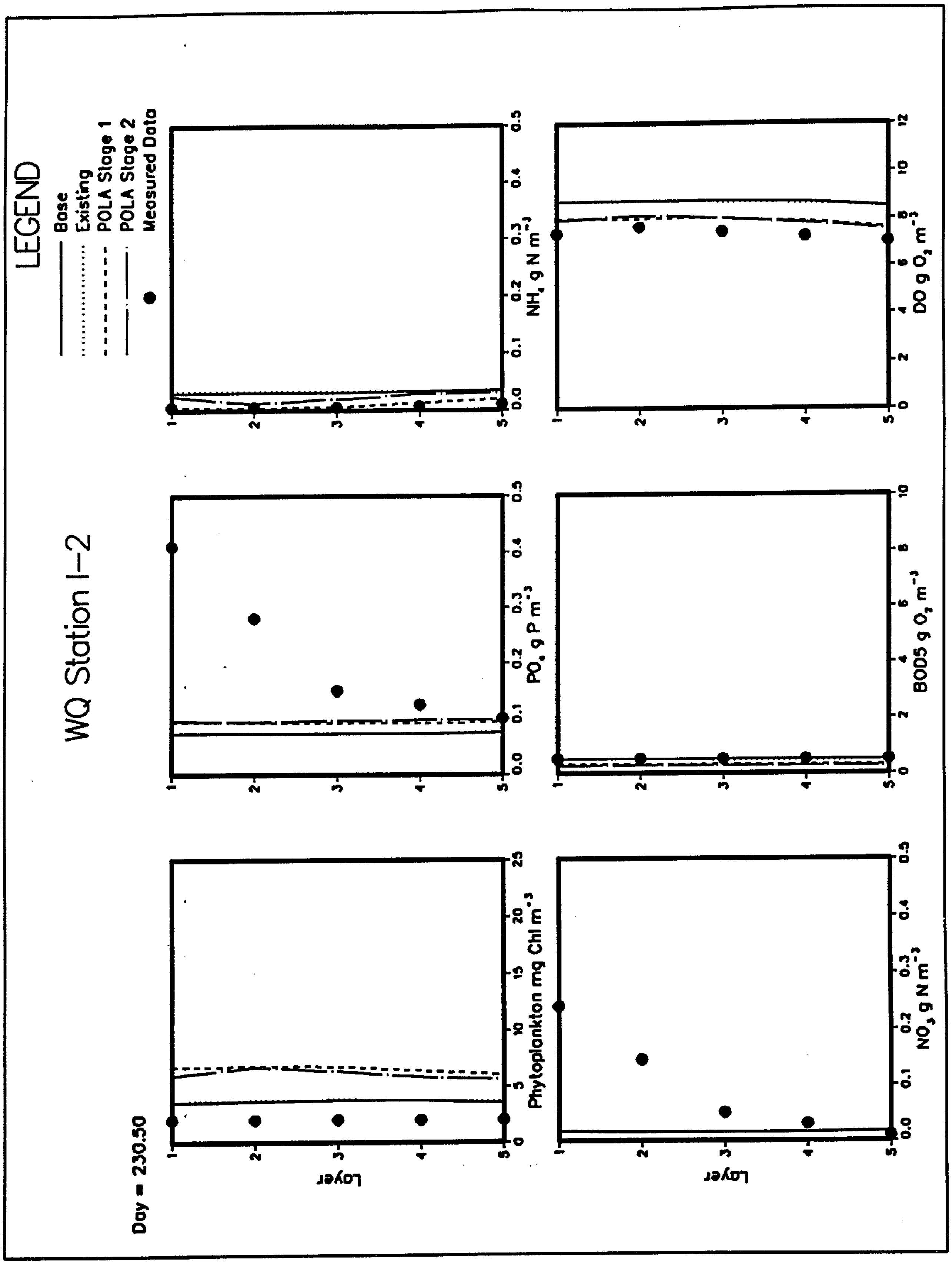
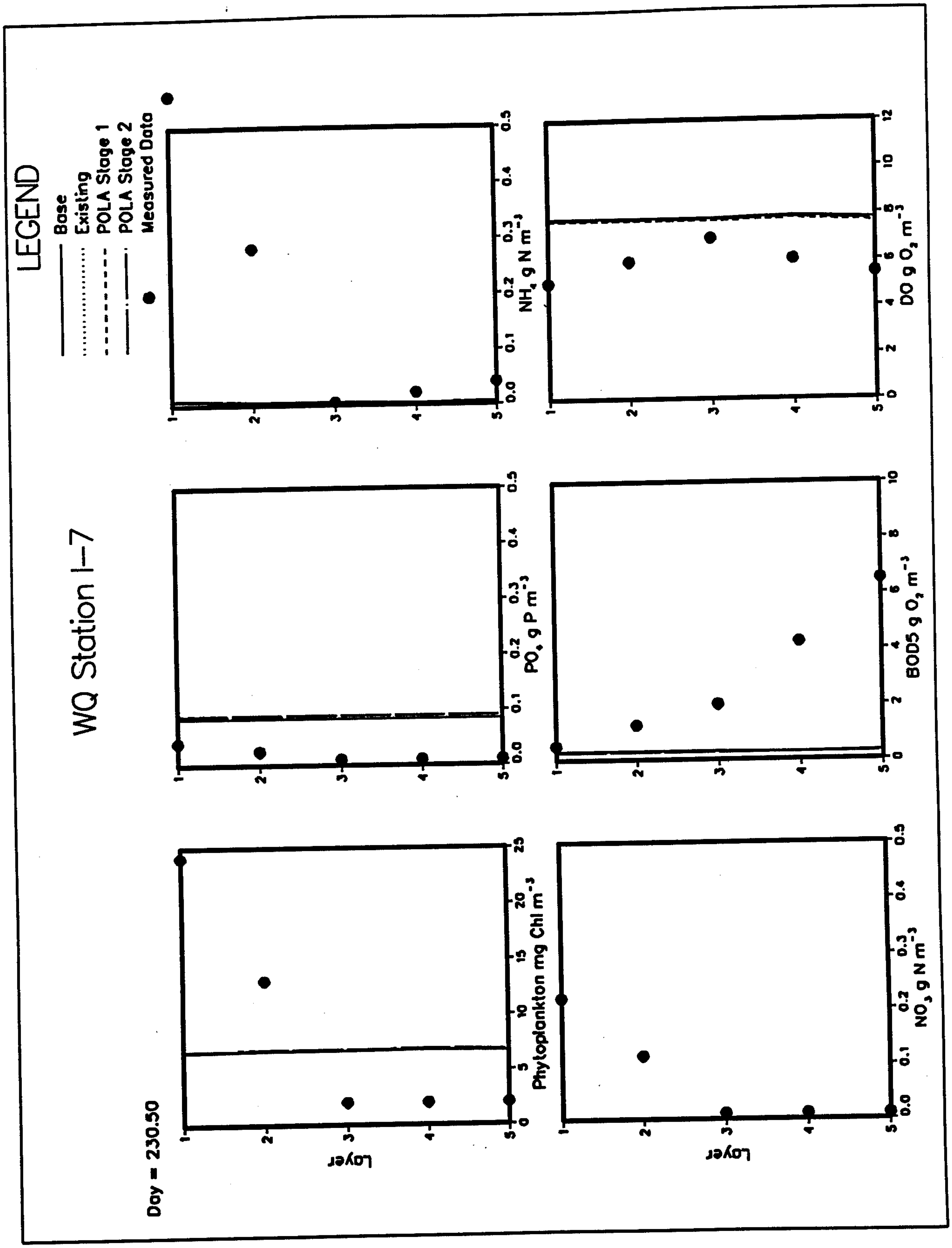
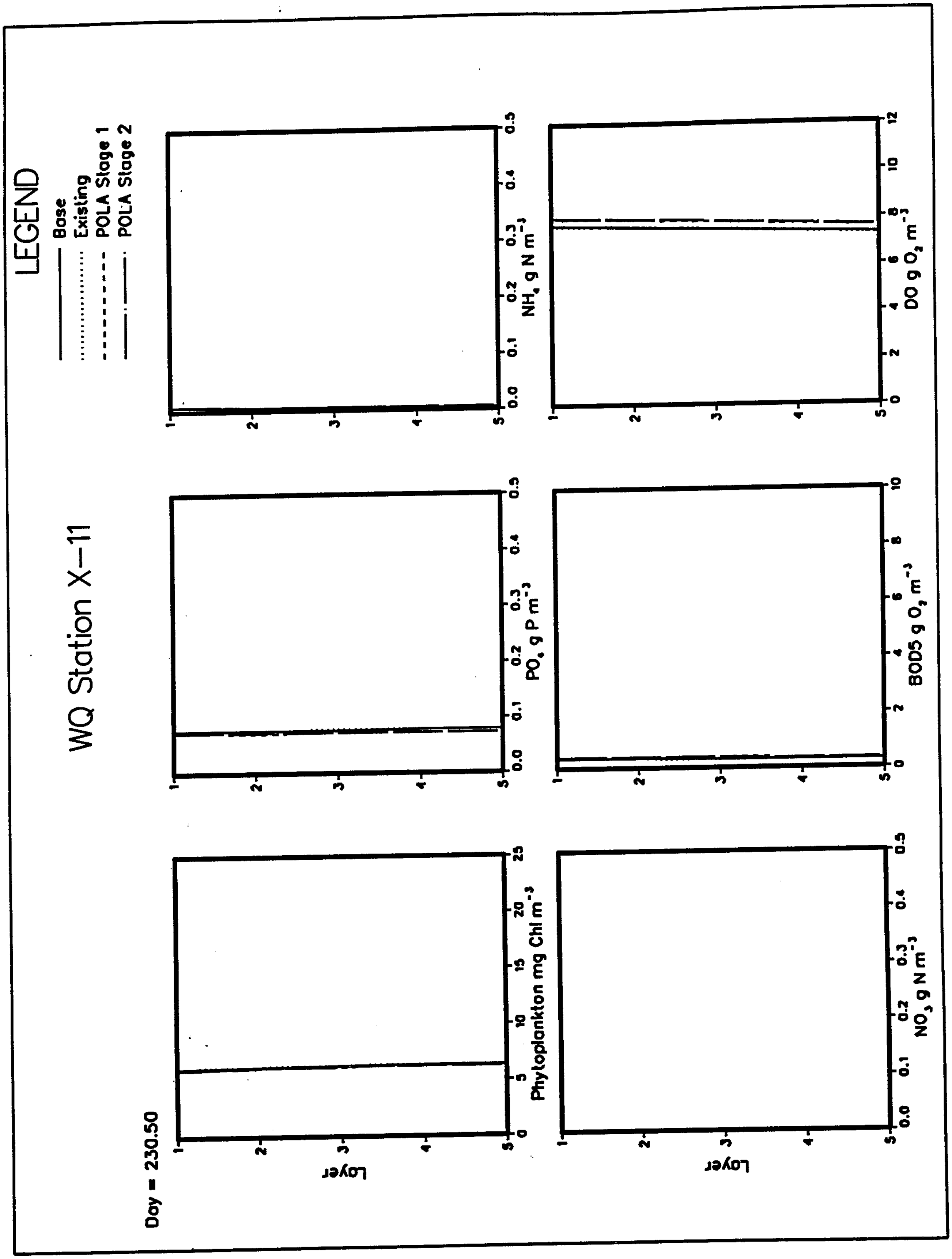

WQ Station I–2
Day = 230.50
LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
Measured Data
Layer
Phytoplankton mg Chl m^-3
PO4 g P m^-3
NH4 g N m^-3
NO3 g N m^-3
BOD5 g O2 m^-3
DO g O2 m^-3

Plate C12



WQ Station I-7
Day = 230.50
LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
Measured Data
Layer
Phytoplankton mg Chl m^-3
PO4 g P m^-3
NH4 g N m^-3
NO3 g N m^-3
BOD5 g O2 m^-3
DO g O2 m^-3



WQ Station X–11
LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
Day = 230.50
Layer
Phytoplankton mg Chl m^{-3}
PO_4 g P m^{-3}
NH_4 g N m^{-3}
NO_3 g N m^{-3}
BOD5 g O_2 m^{-3}
DO g O_2 m^{-3}

Plate C14

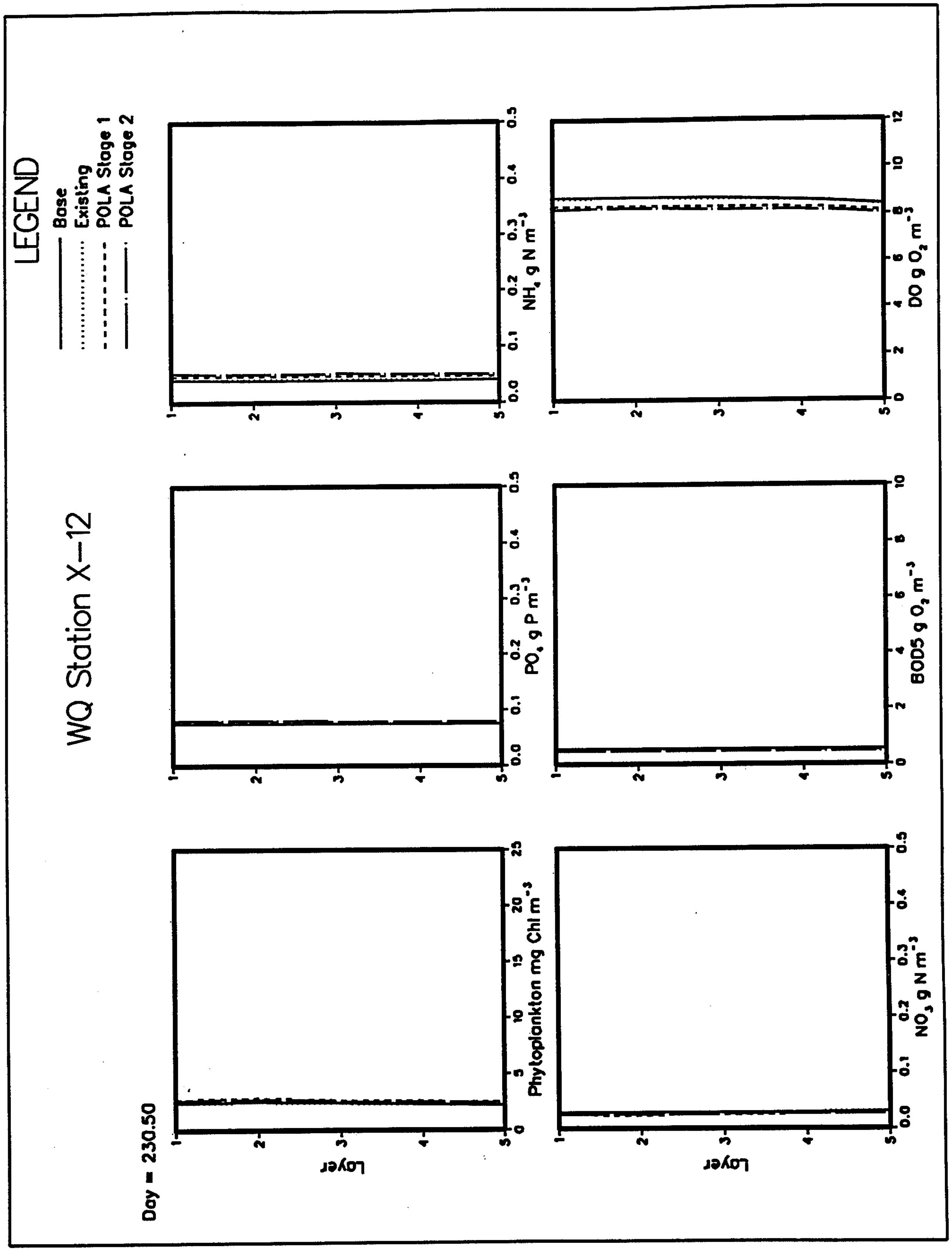
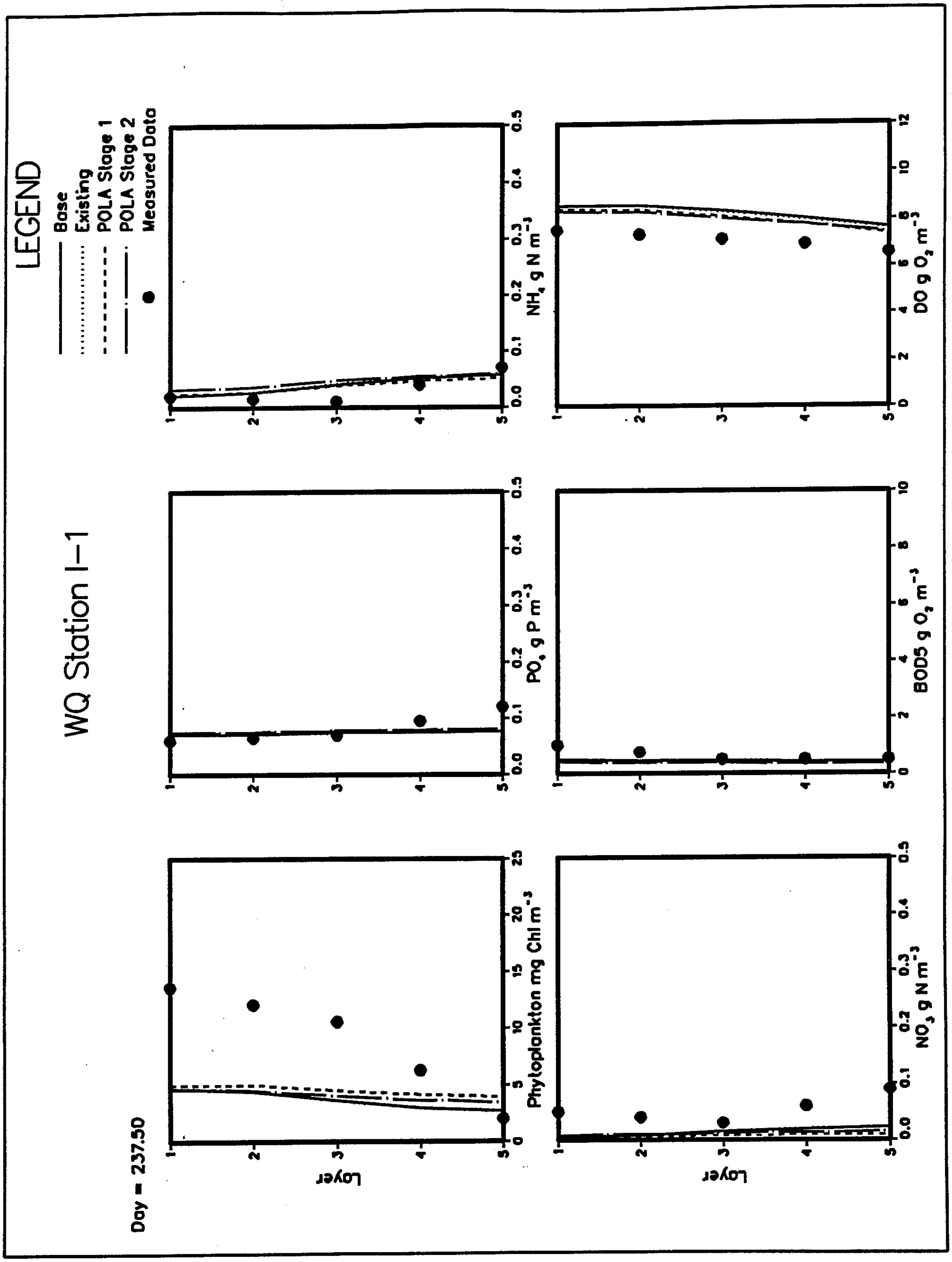
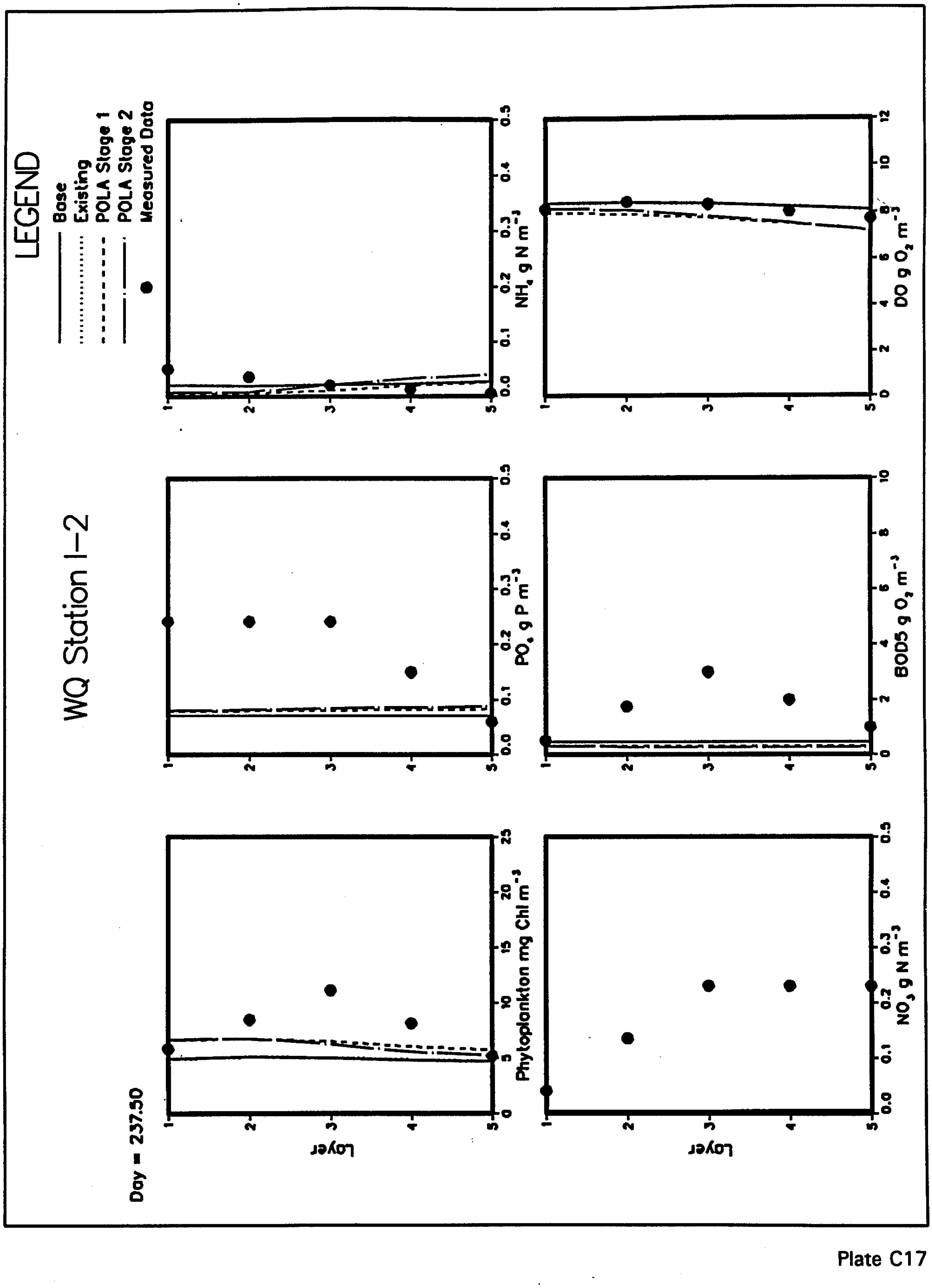

WQ Station X–12
LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
Day = 230.50
Layer
NH_4 g N m^{-3}
PO_4 g P m^{-3}
Phytoplankton mg Chl m^{-3}
DO g O_2 m^{-3}
BOD5 g O_2 m^{-3}
NO_3 g N m^{-3}

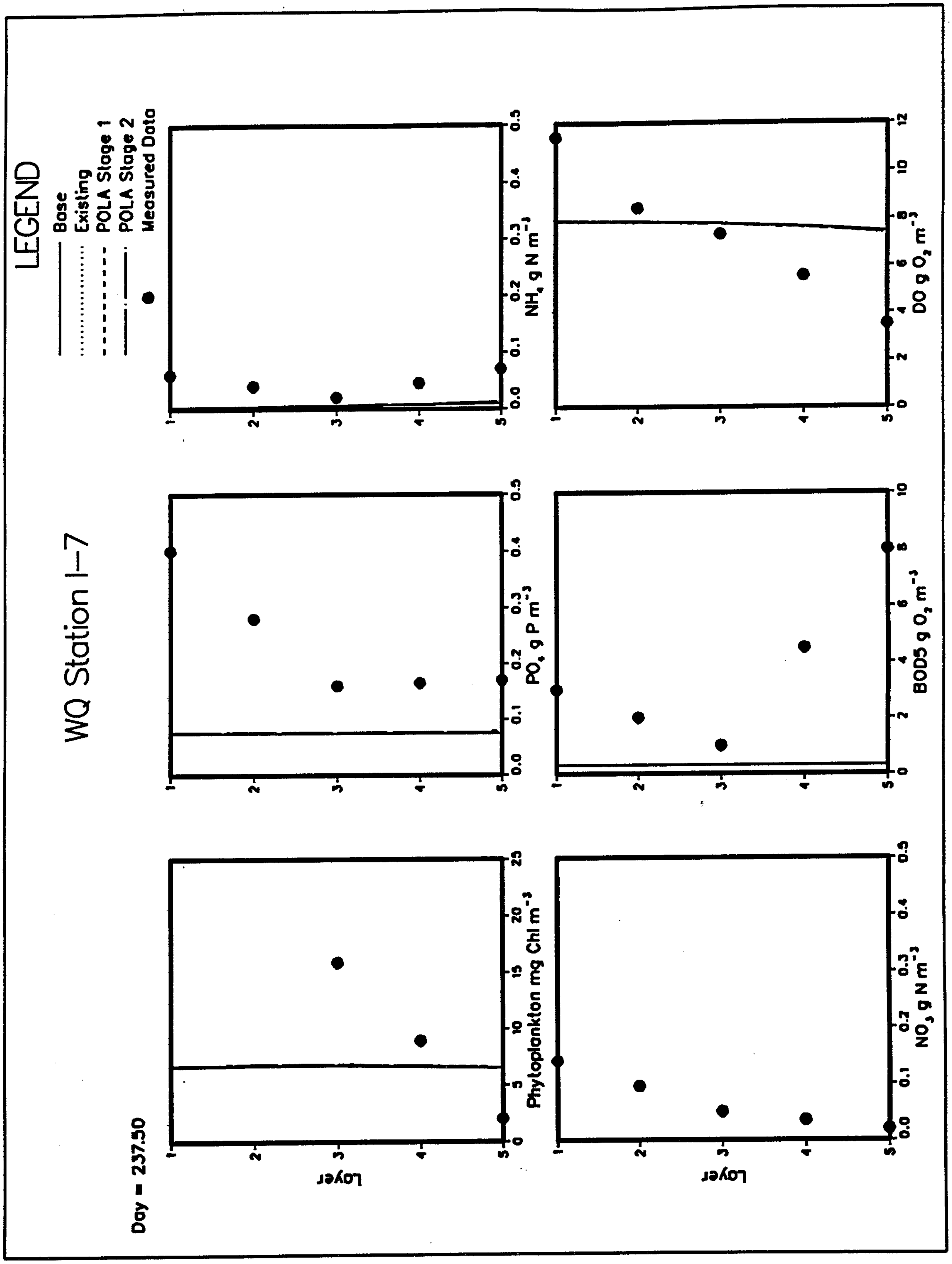
Plate C15



WQ Station I–1
LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
Measured Data
Day = 237.50
Layer
Phytoplankton mg Chl m-3
PO4 g P m-3
NH4 g N m-3
NO3 g N m-3
BOD5 g O2 m-3
DO g O2 m-3

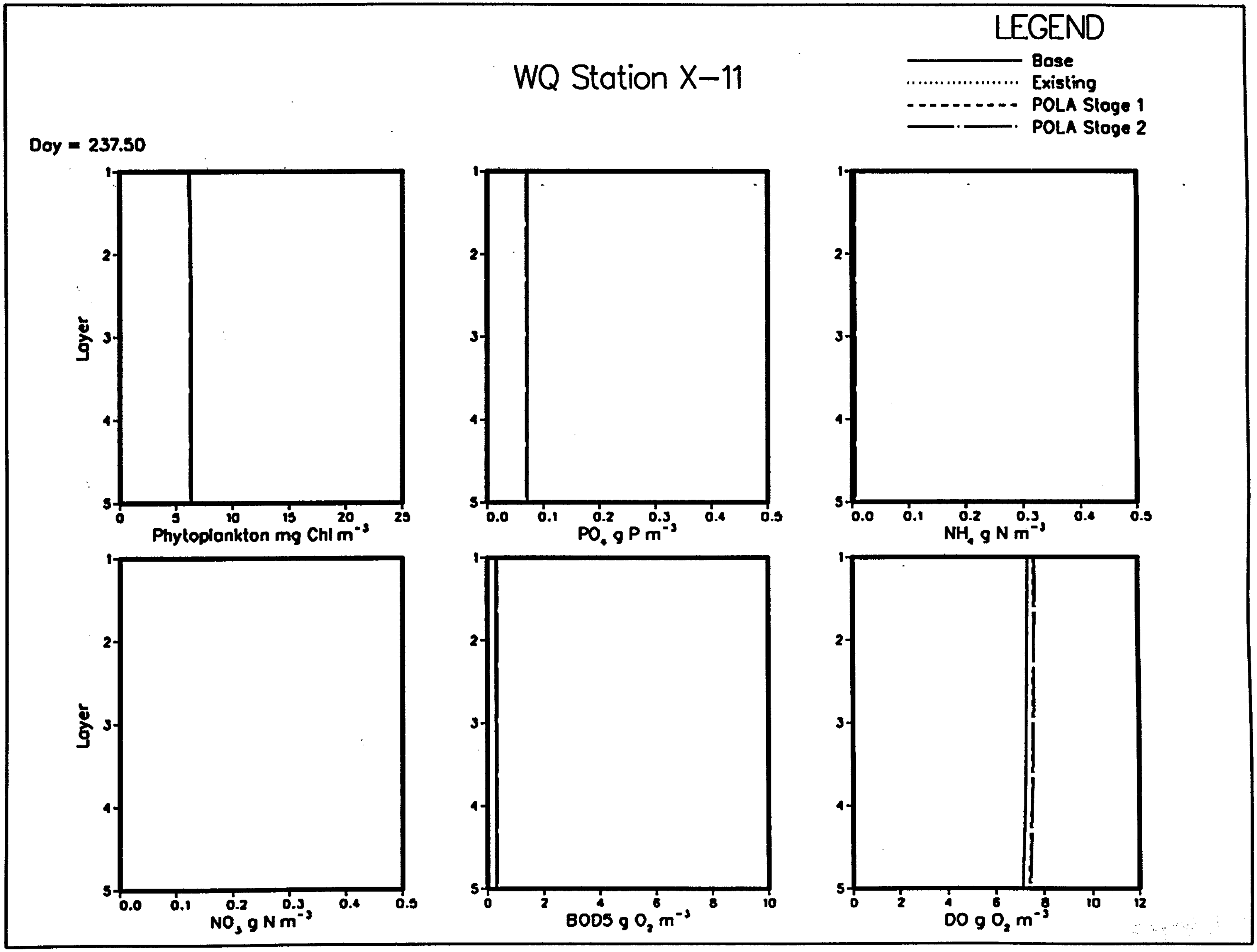


WQ Station I-2
LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
Measured Data
Day = 237.50
Layer
Phytoplankton mg Chl m^-3
PO4 g P m^-3
NH4 g N m^-3
NO3 g N m^-3
BOD5 g O2 m^-3
DO g O2 m^-3



WQ Station I-7
LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
Measured Data
Day = 237.50
Layer
Phytoplankton mg Chl m-3
PO4 g P m-3
NH4 g N m-3
NO3 g N m-3
BOD5 g O2 m-3
DO g O2 m-3

Plate C18



WQ Station X–11
LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
Day = 237.50
Layer
Phytoplankton mg Chl m-3
PO4 g P m-3
NH4 g N m-3
NO3 g N m-3
BOD5 g O2 m-3
DO g O2 m-3

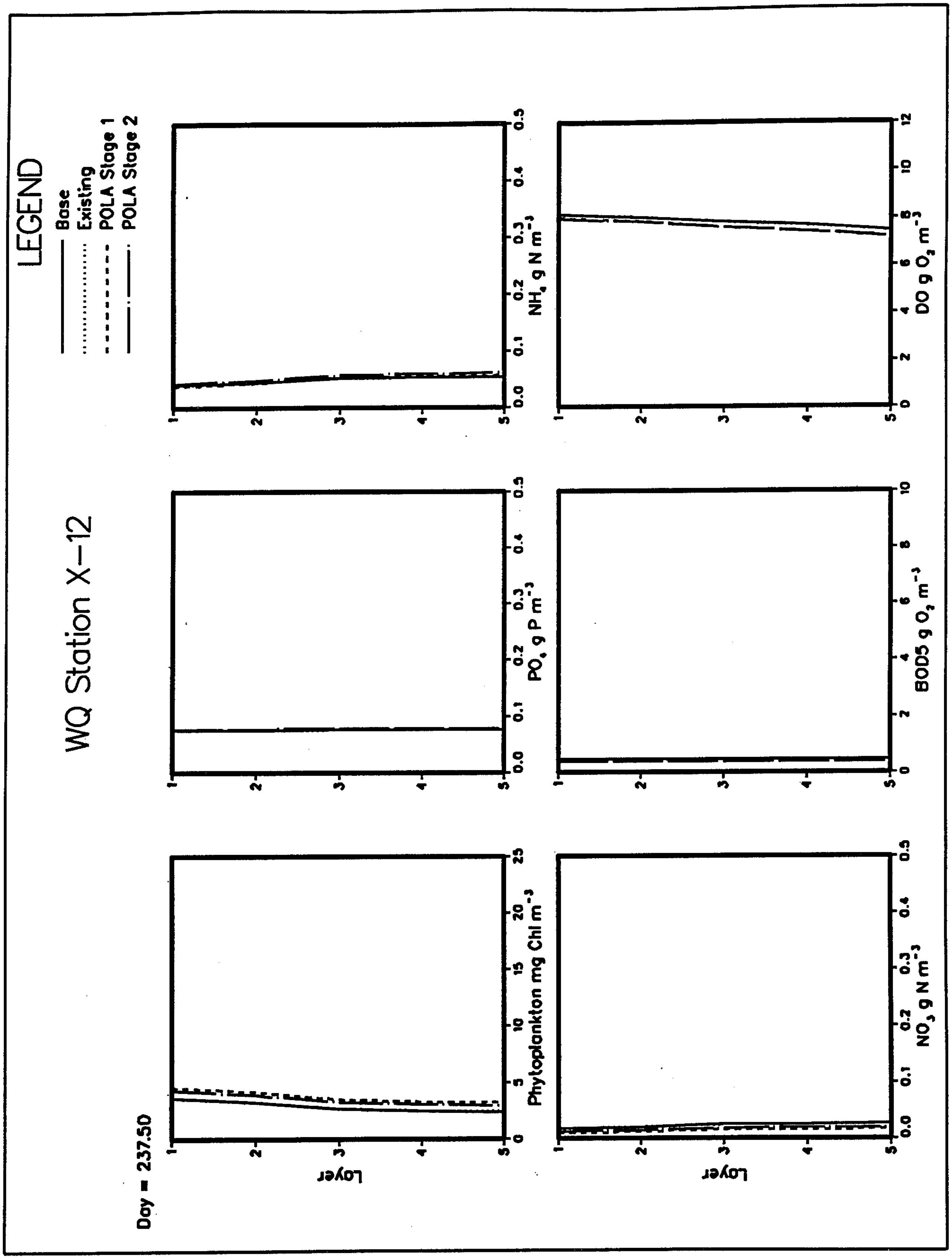

WQ Station X–12
LEGEND
Base
Existing
POLA Stage 1
POLA Stage 2
Day = 237.50
Layer
Phytoplankton mg Chl m^-3
PO_4 g P m^-3
NH_4 g N m^-3
NO_3 g N m^-3
BOD5 g O_2 m^-3
DO g O_2 m^-3

Plate C20